

DRAFT

**Intrinsic Remediation
Engineering Evaluation/Cost Analysis for
the Former AGE Fueling Facility Site**

Volume I: Report



**Seymour Johnson Air Force Base
Goldsboro, North Carolina**

Prepared For

**Air Force Center for Environmental Excellence
Technology Transfer Division
Brooks Air Force Base
San Antonio, Texas**

and

**Seymour Johnson Air Force Base
North Carolina**

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April 1996

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**INTRINSIC REMEDIATION
ENGINEERING EVALUATION/COST ANALYSIS FOR
THE FORMER AGE FUELING FACILITY SITE
VOLUME I**

**SEYMOUR JOHNSON AIR FORCE BASE
GOLDSBORO, NORTH CAROLINA**

April 1996

Prepared for:

**AIR FORCE CENTER FOR ENVIRONMENTAL EXCELLENCE
TECHNOLOGY TRANSFER DIVISION
BROOKS AIR FORCE BASE
SAN ANTONIO, TEXAS**

AND

**SEYMOUR JOHNSON AIR FORCE BASE
NORTH CAROLINA**

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EXECUTIVE SUMMARY

This report presents the results of the investigation performed by Parsons Engineering Science, Inc. (Parsons ES) at Seymour Johnson Air Force Base (AFB), North Carolina to evaluate the use of intrinsic remediation (natural attenuation) with long-term monitoring (LTM) as a remedial option for dissolved benzene, toluene, ethylbenzene, and total xylenes (BTEX) contamination in shallow groundwater. Parsons ES conducted the field investigation during the period between January and July 1995 at the former aerospace ground equipment (AGE) fueling facility site (adjacent to Building 4715). The source of the contamination is assumed to be releases from an abandoned underground storage tank (UST) system that was formerly used to store gasoline, JP-4, and diesel fuel. BTEX and total volatile hydrocarbons (TVH) were determined to be dissolved in groundwater and adsorbed to soils. Residual light non-aqueous phase liquid (LNAPL) was found in the soil column (at the groundwater interface) in the immediate vicinity of the former UST system. Also, mobile LNAPL (free product) was observed in several monitoring points installed during the investigation. This study focused on the impacts of the dissolved BTEX and residual and mobile LNAPL on the shallow groundwater system at the site. Potential electron acceptors and other geochemical parameters were analyzed to quantify ongoing biodegradation.

An important component of this study was an assessment of the potential for contamination in groundwater to migrate from the former AGE fueling facility site to potential receptor exposure points. The Bioplume II model was used to estimate the fate and transport of dissolved BTEX in the shallow saturated zone under the influence of advection, dispersion, sorption, and biodegradation. Whenever possible, input parameters for the Bioplume II model were obtained from data collected by Parsons ES during 1995. Extensive site-specific data were used for model calibration and implementation. Model parameters not measured at the site were either obtained from site characterization data from other sites investigated at Seymour Johnson AFB, or supplemented using established conservative literature values for similar aquifer materials. A comparison to analytical model results is also provided as a check on the Bioplume II model results.

Groundwater analytical results indicate that natural attenuation mechanisms are reducing BTEX concentrations at the site. Fate and transport modeling results suggest that dissolved BTEX contamination present in groundwater will not reach potential exposure points at concentrations exceeding North Carolina groundwater quality standards. The Air Force therefore recommends that intrinsic remediation with LTM be implemented for dissolved BTEX contamination found in groundwater at the former AGE fueling facility site. To enhance these natural processes, the Air Force also recommends installation of a skimming system to remove mobile LNAPL contamination. In the event LTM indicates that the remedial measures are not sufficient to control contaminant migration, additional remedial actions may be required.

The Air Force recommends using six LTM wells to verify Bioplume II model predictions and to monitor long-term migration and degradation of dissolved BTEX. Also, six point-of-compliance (POC) monitoring wells are recommended to establish a

compliance boundary for the site. In order to monitor effectiveness of the intrinsic remediation program, these wells should be sampled annually for 15 years. If the data collected during this period supports the anticipated effectiveness of intrinsic remediation, the sampling frequency could be reduced or eliminated. The groundwater samples should be analyzed for BTEX compounds by US Environmental Protection Agency (USEPA) Method SW8020. If BTEX concentrations in groundwater from the POC wells exceed North Carolina's groundwater quality standards of 1 microgram per liter ($\mu\text{g/L}$) for benzene, 1,000 $\mu\text{g/L}$ for toluene, 29 $\mu\text{g/L}$ for ethylbenzene, or 530 $\mu\text{g/L}$ for total xylenes, additional corrective actions may be required to remediate groundwater at the site.

SECTION 1

INTRODUCTION

Parsons Engineering Science, Inc. (Parsons ES) has prepared this engineering evaluation/cost analysis (EE/CA) report to evaluate the use of intrinsic remediation for remediation of fuel-hydrocarbon-contaminated groundwater near the former Aerospace Ground Equipment (AGE) fueling facility adjacent to building 4715 located at Seymour Johnson Air Force Base (AFB), Goldsboro, North Carolina. Subsurface investigations performed in the vicinity of a former underground storage tank (UST) area have indicated that fuels have been released into the soil and shallow groundwater at the site. The main emphasis of the work described herein was to evaluate the potential for natural biodegradation mechanisms to reduce dissolved fuel hydrocarbon concentrations in groundwater to levels that meet state-specified groundwater protection standards. As used throughout this report, the term "intrinsic remediation" refers to a management strategy that relies on natural attenuation mechanisms to control exposure of potential receptors to concentrations of benzene, toluene, ethylbenzene, and xylenes (BTEX) in the subsurface that exceed regulatory levels of concern. "Natural attenuation" refers to the actual processes (e.g., sorption, dispersion, and biodegradation) that facilitate intrinsic remediation.

Intrinsic remediation is an innovative remedial approach that relies on natural attenuation to remediate contaminants dissolved in groundwater. Mechanisms of natural attenuation of BTEX dissolved in groundwater include advection, dispersion, dilution from recharge, sorption, volatilization, and biodegradation. Of these processes, biodegradation is the only mechanism working to transform contaminants into innocuous byproducts. Intrinsic bioremediation occurs when indigenous microorganisms work to bring about a reduction in the total mass of contamination in the subsurface without the addition of nutrients. Patterns and rates of intrinsic remediation can vary markedly from site to site depending on governing physical chemical processes.

1.1 SCOPE AND OBJECTIVES

Parsons ES was retained by the United States Air Force Center for Environmental Excellence (AFCEE) to conduct site characterization and groundwater modeling in support of intrinsic remediation with long-term monitoring (LTM) as part of a nationwide, multi-site demonstration program. The intent of the intrinsic remediation demonstration program sponsored by AFCEE is to develop a systematic process for scientifically investigating and documenting naturally occurring subsurface attenuation processes that can be factored into overall site remediation plans. The objective of the program and this specific demonstration is to provide solid evidence of intrinsic remediation of dissolved fuel hydrocarbons in groundwater so that this information can be used by the Base and its prime environmental contractor(s) to develop an effective groundwater remediation strategy. As a result, these demonstrations are not necessarily intended to fulfill specific federal or state requirements regarding site assessments,

remedial action plans (RAPs), or other such mandated investigations and reports. A secondary goal of this multi-site initiative is to provide a database from multiple sites that demonstrates that natural processes of contaminant degradation often can reduce contaminant concentrations in groundwater to below acceptable cleanup standards before potential receptor exposure pathways are completed.

The scope of work for this project includes the following tasks:

- Reviewing existing hydrogeologic data and soil and groundwater quality data for the site;
- Conducting supplemental site characterization activities to determine the nature and extent of soil and groundwater contamination and to collect geochemical data in support of intrinsic remediation;
- Developing a conceptual hydrogeologic model of the shallow saturated zone, including the current distribution of contaminants;
- Evaluating site-specific data to determine whether natural processes of contaminant attenuation and destruction are occurring in site groundwater;
- Using the Bioplume II numerical model to simulate the fate and transport of fuel hydrocarbons in groundwater under the influence of biodegradation, advection, dispersion, and adsorption;
- Evaluating a range of model input parameters to determine the model sensitivity to those parameters and to consider several contaminant fate and transport scenarios;
- Determining whether naturally occurring processes are sufficient to minimize the dissolved BTEX plume expansion so that groundwater quality standards are met at a downgradient point of compliance (POC);
- Conducting a preliminary exposure pathways analysis for fuel hydrocarbon contamination in groundwater and potential receptors;
- Developing remedial action objectives (RAOs) and reviewing available remedial technologies;
- Using model results to recommend the most appropriate remedial option based on specific effectiveness, implementability, and cost criteria; and
- Providing a LTM plan that includes establishing POC wells, and a sampling and analysis plan.

Parsons ES and the US Army Corps of Engineers (USACE) performed site characterization activities for the intrinsic remediation investigation. The activities, conducted in January 1995, consisted of cone penetrometer testing (CPT) in conjunction with laser-induced fluorometry (LIF) using the USACE cone penetrometer truck. Initially, site lithology and the extent of the mobile light nonaqueous-phase liquid (LNAPL) plume were determined by using CPT and LIF during concurrent penetrometer pushes. Evaluation of these data determined the need for additional soil and groundwater sampling locations. In April 1995, Parsons ES used the AFCEE Geoprobe[®] truck to

conduct additional soil and groundwater sampling and to install groundwater monitoring points. Permanent and temporary monitoring points were then installed to characterize the site hydrogeology and groundwater geochemistry and to further delineate the contaminant plume. Parsons ES then performed soil and groundwater sampling, and water level and LNAPL thickness measurements at the Geoprobe® test locations.

The Bioplume II model code and site-specific data were used to develop a contaminant fate and transport model for the site. Using the results of the model, a preliminary exposure pathways analysis was performed. As part of the EE/CA, this modeling effort had three primary objectives: 1) to predict the future extent and concentration of a dissolved contaminant plume by modeling the combined effects of advection, dispersion, sorption, and biodegradation; 2) to assess the possible threat to potential downgradient receptors by conducting a preliminary exposure assessment; and 3) to provide technical support during regulatory negotiations for intrinsic remediation with LTM, as appropriate.

Several remedial options were evaluated during this EE/CA, including mobile LNAPL recovery, soil vapor extraction (SVE), bioslurping, bioventing, biosparging, and natural contaminant attenuation with LTM. Hydrogeologic and groundwater chemical data necessary to evaluate the various remedial options were collected under this program. However, the field work conducted under this program was oriented toward the collection of hydrogeologic data to be used as input into Bioplume II and to support intrinsic remediation.

This report contains nine sections, including this introduction, and six appendices. Section 2 summarizes site characterization activities. Section 3 summarizes the physical characteristics of the study area. Section 4 describes the nature and extent of soil and groundwater contamination and the geochemistry of soil and groundwater at the site. Section 5 describes the conceptual hydrogeologic model developed for the site, Bioplume II model assumptions and input parameters, sensitivity analyses, and the results of the Bioplume II modeling. Section 6 describes remedial alternatives evaluation criteria and presents a comparative analysis of selected options. Section 7 presents the LTM plan for the site. Section 8 presents the conclusions of this work, and Section 9 lists the references used to develop this document. Appendix A contains boring logs and well completion diagrams. Appendix B contains soil and groundwater analytical results. Appendix C contains gridded model input parameters and model calibration results. Appendix D contains a diskette with the Bioplume II model input and output in ASCII format. Appendix E contains the results for analytical models used for comparison to Bioplume II. Appendix F contains the costing worksheets and present worth calculations developed during the comparative analysis of selected remedial options.

1.2 FACILITY BACKGROUND

Seymour Johnson AFB is located near the city of Goldsboro, approximately 50 miles southeast of Raleigh, North Carolina. The Base is bounded on the southwest by the Neuse River, and on the northwest by Stoney Creek. Figure 1.1 is a regional location map showing the position of Seymour Johnson AFB relative to the surrounding area. Seymour Johnson AFB contains approximately 3,216 acres of land in the main Base area.

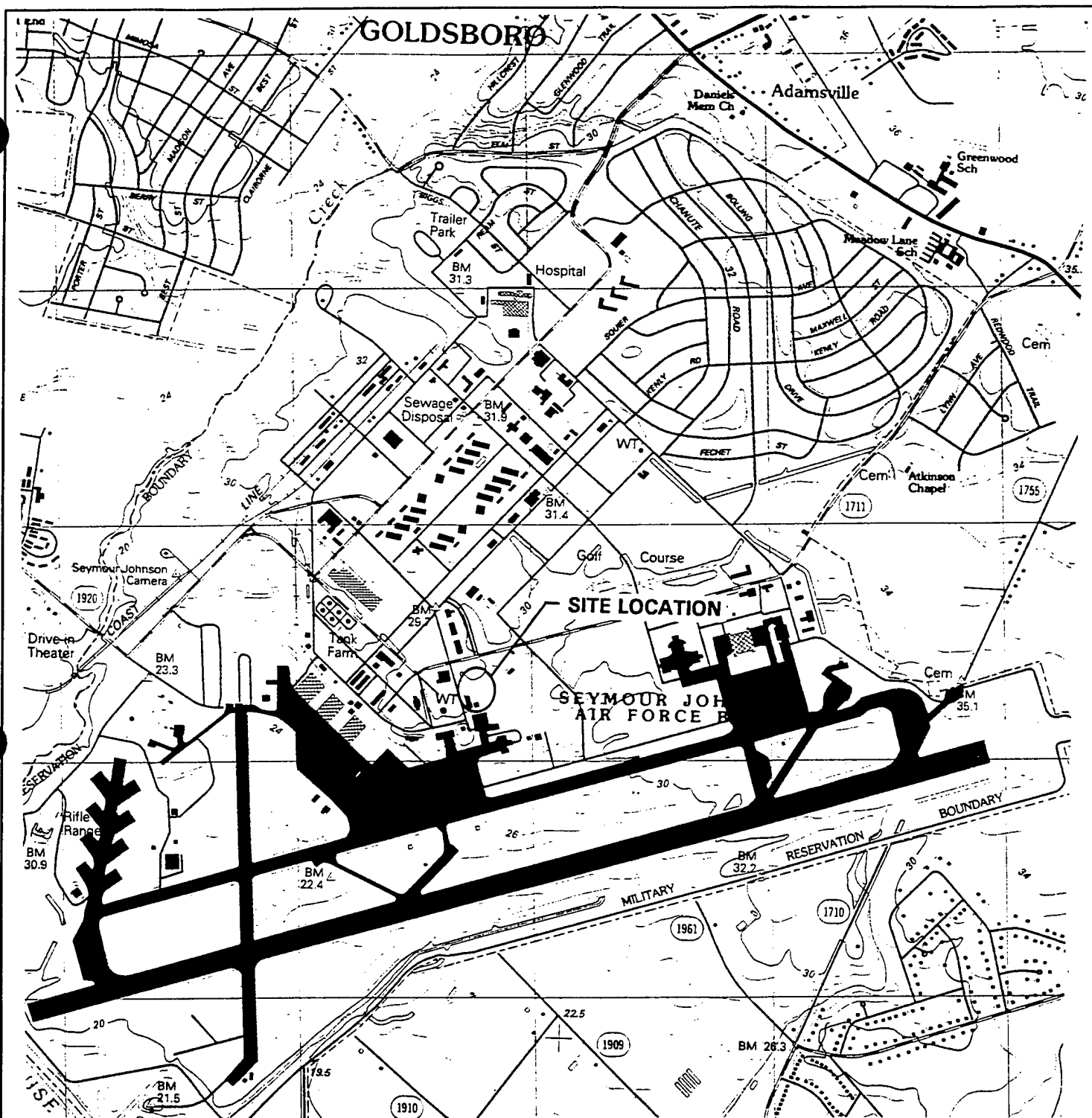


Figure 1.1

REGIONAL LOCATION MAP

**Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC**



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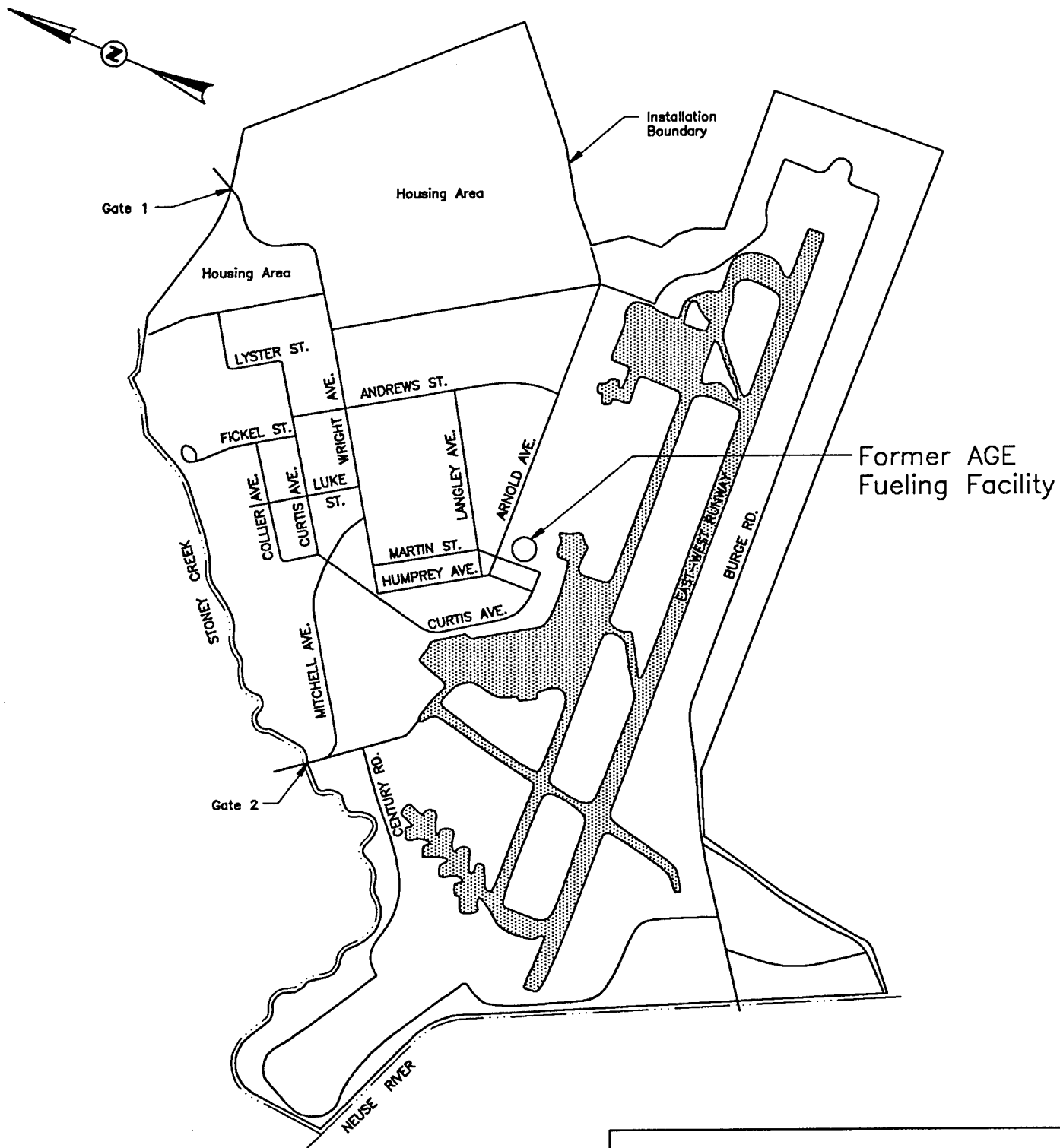
Gary, North Carolina

Seymour Johnson AFB was established in 1942 as a technical school and training facility. At the end of World War II, the Base became an Army Air Force Separation Center, and in 1946 was deactivated. In 1949, the property was deeded to the city of Goldsboro. Piedmont Airlines used the air field for regular commercial flights from 1950 to 1953. During this time, other Base facilities were leased to private industry for warehousing, light manufacturing, and housing. In 1952, the city of Goldsboro returned the property to the federal government, and in 1956 the Base was reopened as a Tactical Air Command Base. The Base now primarily serves as the home of the Air Combat Command's 4th Fighter Wing.

The former AGE fueling facility is located in the central portion of the Base, along Martin Street and adjacent to Building 4715 (Figures 1.2 and 1.3). The facility served as a fueling station for generators, tow trucks, and other support vehicles and equipment. The facility was taken out of service for fueling operations in 1994, when the site's fueling facilities (including USTs, piping, and dispensers) were removed and closed. The facility formerly utilized three USTs for the storage of various fuels: one 2,000-gallon JP-4 UST, one 2,000-gallon gasoline UST, and one 2,000-gallon diesel fuel UST. The approximate former location of all the tanks is shown on Figure 1.3. Soil and groundwater contamination were detected at the site during the excavation of the USTs in 1994. The contamination is attributed to leaks in the former fuel storage and distribution system.

Between January 19 and 25, 1995, Parsons ES and USACE performed a preliminary screening of the subsurface conditions at the former AGE fueling facility. The USACE Site Characterization and Analysis Penetrometer System (SCAPS) truck was employed to perform CPT, LIF, soil sampling, and installation of direct-push monitoring points. This preliminary screening provided data used to evaluate the extent of petroleum contamination in the subsurface, as well as site lithology. In April 1995, Parsons ES conducted supplemental site characterization activities using the AFCEE Geoprobe® to collect soil and groundwater samples and to install additional monitoring points. Currently, Base personnel are using a bailer to remove between 0.25 and 0.5 gallon of LNAPL from monitoring point MW-13 once each week.

Site characterization had not been performed at the former AGE fueling facility prior to the investigations performed by Parsons ES; however, site investigations have been performed on numerous other locations at the Base. In addition to the data collected during the preliminary subsurface screening, reports of investigations under the Air Force Installation Restoration Program (IRP) were reviewed to formulate the conceptual model presented in Section 5.



2500' 1250' 0 2500'

Approximate Scale in Feet

Figure 1.2

SITE LOCATION MAP

Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC



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Cary, North Carolina

Sources: Law Environmental, 1992, and Seymour Johnson AFB.

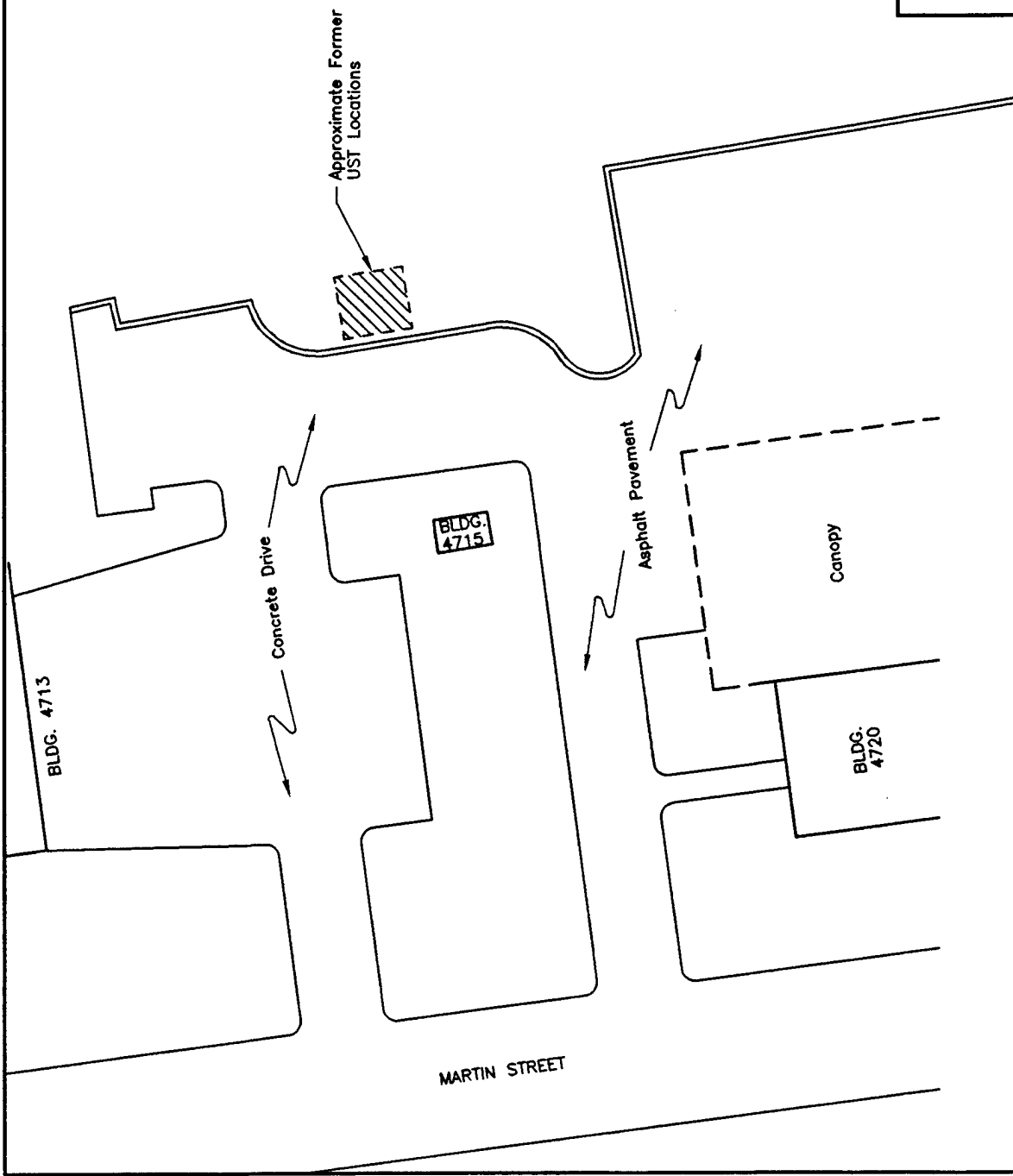


Figure 1.3

SITE LAYOUT

Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC



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Cary, North Carolina

SECTION 2

SITE CHARACTERIZATION ACTIVITIES

This section presents the methods and procedures used by Parsons ES to collect the site-specific data at Seymour Johnson AFB for the intrinsic remediation demonstration. The goals of the site characterization activities were to delineate the extent of contamination (residual LNAPL, mobile LNAPL, and dissolved BTEX) and to collect hydrogeologic and geochemical data used to evaluate intrinsic remediation as well as other remedial alternatives. Data collected under this program were used to aid with interpretation of the physical setting (Section 3), contaminant distribution (Section 4), and to develop the conceptual site model (Section 5).

For the purposes of this report, the term "drilling" is used generally to represent CPT/LIF testing and monitoring point installation using direct-push technologies (i.e., the Geoprobe® system) and/or hand auger. To minimize confusion among CPT/LIF test points and CPT-installed monitoring points, a single prefix (CPT) was used to label all CPT/LIF test point locations and monitoring points installed with the cone penetrometer rig. Monitoring points installed using the Geoprobe® system or hand auger were labeled with the prefix "MW", and all locations used for soil sampling only were labeled with the prefix "SS". The field log books and laboratory reports in some cases include additional prefixes to distinguish among sample types. Monitoring point construction details, drilling locations, and soil sampling intervals are presented in Table 2.1. Sampling locations are shown on Figure 2.1.

Parsons ES collected the following physical, chemical, and hydrogeologic data during the field work phase of the EE/CA:

- Detailed analysis of subsurface media;
- Estimation of extent and thickness of LNAPL in monitoring points;
- Depth from measurement datum to the water table in monitoring points;
- Location of potential groundwater recharge and discharge areas;
- BTEX, total extractable petroleum hydrocarbon (TEH), and total volatile petroleum hydrocarbon (TVH) concentrations in soil;
- Total organic carbon (TOC) concentrations in select soil samples;
- Dissolved oxygen (DO), nitrate, nitrite, total iron, ferrous iron, manganese, sulfate, sulfide, chloride, carbon dioxide, methane, and ammonia concentrations in groundwater;
- Temperature, reduction/oxidation (redox) potential, conductance, total alkalinity, and pH of groundwater; and
- BTEX, trimethylbenzene (TMB), tetramethylbenzene (TEMB), TEH, and TVH concentrations in groundwater,

TABLE 2.1
CPT, GEOPROBE®, AND MONITORING POINT COMPLETION SUMMARY
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY
SEYMOUR JOHNSON AFB, NORTH CAROLINA

Sample Location ^v	Northing (ft)	Easting (ft)	CPT ^v Profile Available (Y/N)	LIF ^v Profile Available (Y/N)	Soil Sample ^v Interval (ft bls) ^v	Datum Elevation ^v (ft) ^v	Ground Elevation (ft)	Total Depth (ft bls)	Inner Well Diameter (inches)	Screen Length (ft)	Depth to Screen		Permanent or Temporary (P/T)
											Top (ft bls)	Base (ft bls)	
CPT Test Locations													
CPT-1	4950.65	5017.01	N	N	NS ^v	NA ^v	97.85	NA	NA	NA	NA	NA	T
CPT-2	4947.73	5017.48	Y	Y	NS	NA	97.93	33.00	NA	NA	NA	NA	T
CPT-3	4930.43	5092.56	Y	Y	NS	NA	98.61	30.00	NA	NA	NA	NA	T
CPT-4	5014.23	5062.67	Y	Y	NS	NA	97.19	30.00	NA	NA	NA	NA	T
CPT-5	5024.73	5016.46	Y	Y	NS	NA	96.61	30.00	NA	NA	NA	NA	T
CPT-6	4954.09	5055.77	Y	Y	NS	NA	98.53	30.00	NA	NA	NA	NA	T
CPT-7	4967.23	5102.77	Y	Y	NS	NA	97.84	30.00	NA	NA	NA	NA	T
CPT-8	4895.66	5023.63	Y	Y	NS	NA	98.87	30.00	NA	NA	NA	NA	T
CPT-9	4897.77	5024.17	N	N	16.0 - 16.5	NA	98.83	16.50	NA	NA	NA	NA	T
CPT-10	NM ^v	NM	Y	Y	NS	NA	NM	30.00	NA	NA	NA	NA	Covered ^v
CPT-11	NM	NM	Y	Y	NS	NA	NM	30.00	NA	NA	NA	NA	Covered
CPT-12	NM	NM	Y	Y	NS	NA	NM	30.00	NA	NA	NA	NA	Covered
CPT-13	NM	NM	N	N	8.0 - 8.5	NA	NM	8.50	NA	NA	NA	NA	Covered
CPT-14	NM	NM	N	N	8.5 - 9.0	NA	NM	9.00	NA	NA	NA	NA	Covered
CPT-15	NM	NM	N	N	13.5 - 14.0	NA	NM	14.00	NA	NA	NA	NA	Covered
CPT-16	4923.11	5073.12	N	N	NS	98.76	NM	15.00	0.50	3.28	11.72	15.00	P
CPT-17	5009.71	5051.56	N	N	NS	97.37	NM	15.00	0.50	3.28	11.72	15.00	P
CPT-18	4924.97	4945.89	N	N	NS	98.11	NM	15.00	0.50	3.28	11.72	15.00	P
CPT-19	5028.41	4942.82	N	N	NS	96.86	NM	15.00	0.50	3.28	11.72	15.00	P
Geoprobe Test Locations													
MW-1	5047.02	5067.16	NA	NA	12.0 - 14.0	NA	NM	14.00	NA	3.28	10.72	14.00	Abandoned
MW-2	4947.73	5026.15	NA	NA	9.5 & 10.5	97.76	NM	12.00	1.00	5.00	7.00	12.00	P
MW-3	4993.40	4998.74	NA	NA	NS	96.78	NM	12.00	1.00	5.00	7.00	12.00	P
MW-4	4952.99	5055.65	NA	NA	12 & 13.5	98.44	NM	15.00	1.00	5.00	10.00	15.00	P
MW-5	4958.23	5094.97	NA	NA	13.0 - 14.5	97.93	NM	14.75	0.50	5.00	9.75	14.75	P
MW-6	4892.38	5103.58	NA	NA	15 & 16	98.22	NM	16.00	0.50	5.00	11.00	16.00	P

TABLE 2.1 (Continued)
CPT, GEOPROBE®, AND MONITORING POINT COMPLETION SUMMARY
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY
SEYMOUR JOHNSON AFB, NORTH CAROLINA

Sample Location ^{a/}	Northing (ft)	Easting (ft)	CPT ^{b/} Profile Available (Y/N)	LIF ^{c/} Profile Available (Y/N)	Soil Sample ^{d/} Interval (ft bls) ^{e/}	Datum Elevation ^{f/} (ft) ^{g/}	Ground Elevation (ft)	Total Depth (ft bls)	Inner Well Diameter (inches)	Screen Length (ft)	Depth to Screen		Permanent or Temporary (P/T)
											Top (ft bls)	Base (ft bls)	
Geoprobe Test Locations													
MW-7	4891.88	5017.81	NA	NA	NS	98.64	NM	16.00	0.50	5.00	11.00	16.00	P
MW-8	4960.16	4933.56	NA	NA	11.0 - 12.0	97.98	NM	13.00	1.00	5.00	8.00	13.00	P
MW-9	4934.78	4892.90	NA	NA	15.0 - 16.0	99.23	NM	12.00	0.50	5.00	7.00	12.00	T
MW-10	5001.13	4747.02	NA	NA	10 & 11	98.08	NM	12.50	0.50	5.00	7.50	12.50	P
MW-11	4924.06	5023.27	NA	NA	11.5 - 13.5	98.52	NM	16.00	0.50	5.00	11.00	16.00	P
MW-12	4948.83	5033.66	NA	NA	NS	98.57	NM	13.00	2.00	5.00	8.00	13.00	P
MW-12D	4949.36	5035.68	NA	NA	NS	NA	NM	17.00	0.38	0.50	16.50	17.00	P
MW-13	4966.32	4990.96	NA	NA	NS	96.64	NM	11.00	2.00	5.00	6.00	11.00	P
MW-14	NM	NM	NA	NA	NS	98.99	NM	10.50	1.00	5.00	5.50	10.50	P
MW-15	NM	NM	NA	NA	NS	99.66	NM	13.00	1.00	5.00	8.00	13.00	P
MW-16	NM	NM	NA	NA	NS	98.08	NM	12.00	1.00	5.00	7.00	12.00	P
MW-17	NM	NM	NA	NA	NS	97.38	NM	15.00	1.00	5.00	10.00	15.00	P
MW-18	NM	NM	NA	NA	NS	98.34	NM	15.00	1.00	5.00	10.00	15.00	P
MW-19	NM	NM	NA	NA	NS	98.13	NM	14.00	1.00	5.00	9.00	14.00	P
SS-1	NM	NM	NA	NA	11.5 & 16	NA	NM	18.00	NA	NA	NA	NA	T
SS-2	NM	NM	NA	NA	11.5 - 13.5	NA	NM	13.50	NA	NA	NA	NA	T
SS-3	NM	NM	NA	NA	9.0 - 11.0	NA	NM	16.30	NA	NA	NA	NA	T

^{a/} See Figure 2.1 for locations.

^{b/} CPT = Cone penetrometer test to determine soil lithology.

^{c/} LIF = Laser-induced fluorescence test.

^{d/} Soil sampled using a Mostap-35 soil sampler at CPT locations, and the Geoprobe® sampler at Geoprobe® locations.

^{e/} ft bls = feet below land surface.

^{f/} Datum elevation refers to top of casing for monitoring points and to land surface for CPT test points.

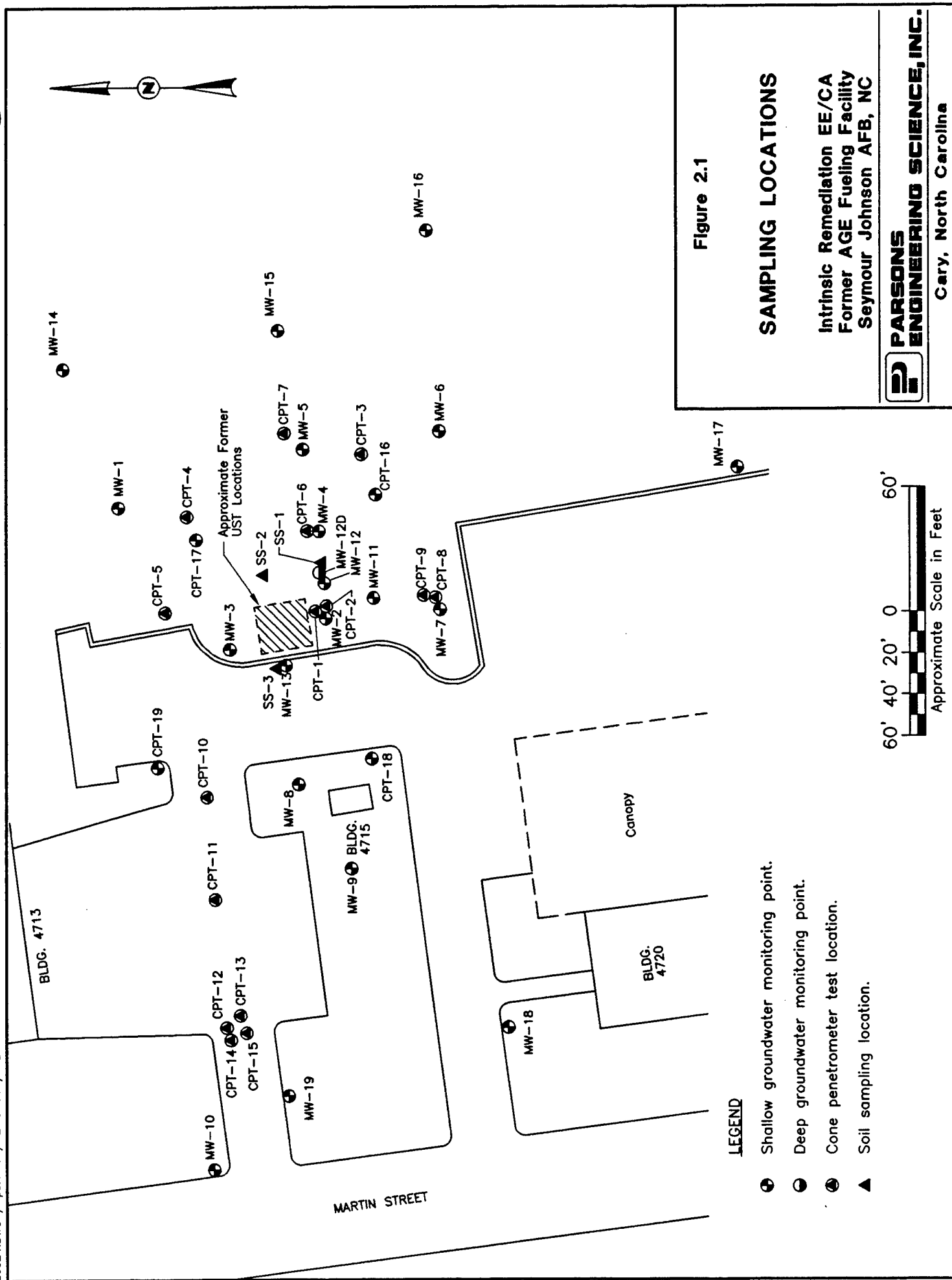
^{g/} ft = feet relative to site benchmark.

^{h/} NS = no sample was collected.

^{i/} NA = not applicable.

^{j/} NM = not measured.

^{k/} Covered with concrete during Base construction activities.



Parsons ES applied several investigative techniques to perform the intrinsic remediation demonstration, with site characterization activities proceeding in four phases. The first phase consisted of characterizing the site lithology and free product plume using the USACE CPT/LIF probe. The second phase consisted of soil sampling using the Geoprobe® system. The third phase included the installation of temporary and permanent groundwater monitoring points using the Geoprobe® system and a hand auger. The fourth phase consisted of groundwater sampling from the monitoring points. Investigative procedures used during these four stages are discussed in Sections 2.1 through 2.4, respectively. Additional details regarding investigative activities are presented in the draft EE/CA work plan (Parsons ES, 1995).

2.1 CONE PENETROMETRY AND LASER-INDUCED FLUOROMETRY SCREENING

CPT-related activities using the USACE SCAPS truck took place between 19 January 1995 and 25 January 1995. CPT, LIF, and soil sampling were accomplished using the procedures described in the following sections. Pushes were performed at the locations labeled CPT-1 through -19 (Figure 2.1). Push statistics are summarized in Table 2.1. CPT and LIF profiles were simultaneously obtained during 10 of the pushes (CPT-2 through CPT-8 and CPT-10 through CPT-12) to characterize subsurface stratigraphy and to evaluate the extent of residual or mobile hydrocarbons in the soils and groundwater. Graphical results of each LIF/CPT push were plotted by USACE staff at the conclusion of each penetration and were available minutes after the completion of each hole. The graphs showed cone resistance, sleeve friction, soil classification, fluorescence intensity, and maximum fluoresced wavelength. Final CPT logs are presented in Appendix A. The remaining 9 pushes were used to collect soil samples and to install 4 groundwater monitoring points.

2.1.1 Pre-Drilling Activities

Prior to drilling mobilization, Parsons ES performed a site walk-through and reviewed surface water drainage maps to determine locations for CPT/LIF test points, soil sampling, and groundwater monitoring points. Parsons ES marked these locations on a map, and Seymour Johnson AFB personnel obtained the necessary utility clearances. The USACE staff used an onsite potable water supply for drilling, equipment cleaning, and grouting. The Seymour Johnson AFB point of contact verified this source prior to use.

2.1.2 Cone Penetrometry Procedures

Cone penetrometry is an expeditious and effective means of analyzing the stratigraphy of a site by measuring the resistance against the conical probe of the penetrometer as it is pushed into the subsurface. Stratigraphy is determined from a correlation of the point stress at the probe tip and frictional stress on the side of the cone. Stratigraphy as determined from the CPT is checked against previous soil data or to soil samples collected to correlate the CPT readings to the lithologies present at the site.

CPT was conducted using the US Army Corps of Engineers' (USACE's) cone penetrometer truck. This equipment consists of an instrumented probe that is forced into the ground using a hydraulic load frame mounted on a heavy truck, with the weight of the truck providing the necessary reaction mass. The penetrometer equipment is housed in a stainless steel, dual-compartment body mounted on a 43,000-pound, triple-axle Kenworth® truck chassis powered by a turbo-charged diesel engine. The weight of the truck and equipment is used as ballast to achieve the overall push capability of 39,000 pounds. This push capacity may be limited in tight soils by the structural bending capacity of the 1.8-inch outside-diameter (OD) push rods, rather than by the weight of the truck. The current 39,000-pound limitation is intended to minimize the possibility of push-rod buckling. Penetration force is supplied by a pair of large hydraulic cylinders bolted to the truck frame. The penetrometer is usually advanced vertically into the soil at a constant rate of 2 centimeters per second (cm/s), although this rate must sometimes be reduced, such as when hard layers are encountered.

The penetrometer probe is of standard dimensions, having a 1.8-inch OD, 60-degree conical point with sacrificial tip, and an 8.0-inch-long by 1.8-inch-OD friction sleeve. Inside the probe, two load cells independently measure the vertical resistance against the conical tip and the side friction along the sleeve. Each load cell is a cylinder of uniform cross-section which is instrumented with four strain gauges in a full-bridge circuit. Forces are sensed by the load cells, and the data are transmitted from the probe assembly via a cable running through the push tubes. The analog data are digitized, recorded, and plotted by computer in the penetrometry truck.

2.1.3 Laser-Induced Fluorometry

The SCAPS LIF system uses a nitrogen-based laser optics fluorometer tool, which scans for fluorescent compounds as it is pushed through the soil. The known propensity of aromatic or chlorinated hydrocarbons to fluoresce under ultraviolet wavelengths has allowed the use of LIF technology in conjunction with CPT technology to detect gross hydrocarbon contamination and soil characteristics simultaneously. The LIF/CPT system has a sapphire window in the side of the CPT probe, which allows a laser to scan the soil for fluorescent compounds as the LIF/CPT penetrometer rod pushes through soil. Assuming that aromatic hydrocarbons are simultaneously solvenated with other fuel-hydrocarbon constituents, the magnitude of aromatic fluorescence is indicative of hydrocarbon contamination in a soil matrix. The push rods act as a conduit for the fiber optic cable and a 6-pair electrical conductor. This wiring connects the laser spectrometer and CPT data acquisition systems to the CPT probe.

The basic components of the LIF instrument are a nitrogen laser, a fiber optic probe, a monochromator for wavelength resolution of the return fluorescence, a photomultiplier tube to convert photons into an electrical signal, a digital oscilloscope for waveform capture, and a control computer. The fiber optic probe for the cone penetrometer consists of delivery and collection optical fibers, a protective sheath, a fiber optic mount within the cone, and a 0.25-inch sapphire window (Figure 2.2). The wavelength used in the USACE CPT LIF system gives the strongest fluorescence signal (attributable to the presence of contamination) for naphthalene and heavier long-chained hydrocarbons. Thus, while the

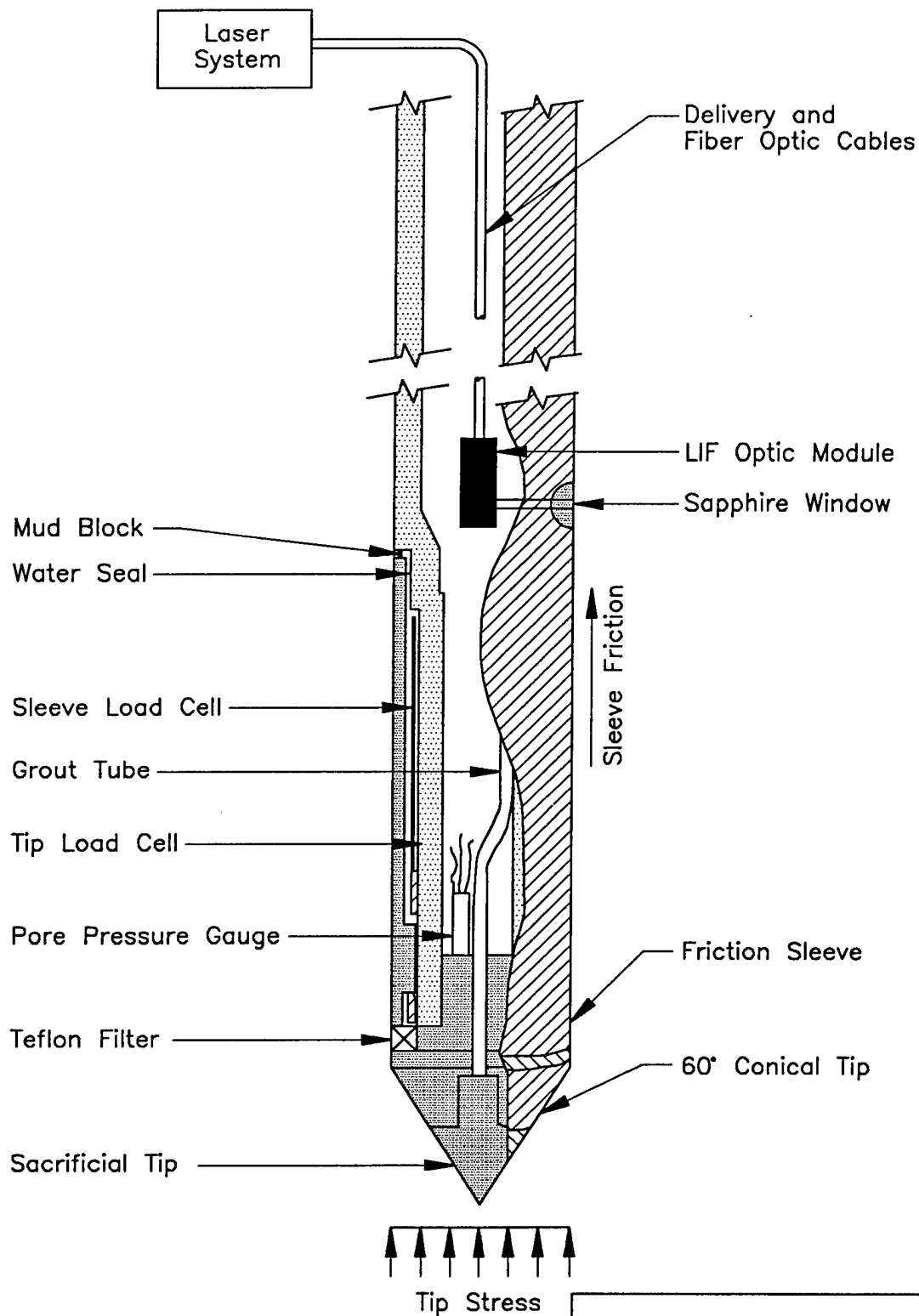


Figure 2.2

SCHEMATIC OF LASER-INDUCED FLUORESCENCE CONE PENETROMETER PROBE

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LIF is not entirely appropriate for detecting the fluorescence of BTEX, it is useful for defining soil contamination because the heavier long-chained hydrocarbons are more likely to sorb to the soil matrix.

2.1.4 Lithologic Correlation

The CPT was used to collect soil samples from 4 pushes (CPT-9, CPT-13, CPT-14, and CPT-15) for lithologic correlation. Sampling information is provided in Table 2.1. The samples were collected using a Hoggen-Toggler[®] sampling device, which can be used to collect undisturbed soil samples at any desired depth within the range of the driving apparatus. The sampler is coupled to the penetrometer rod and pushed into the soil with the CPT truck. With the Hoggen-Toggler[®] cone in the closed position, soil is prevented from entering the sampling tube until the desired depth is achieved. When the sampler has been pushed to the depth at which the soil sample is to be taken, the sampling unit is raised a few inches and the Hoggen-Toggler[®] apparatus is opened. The open Hoggen-Toggler[®] is pushed to fill with soil, then pulled from the ground as quickly as possible. The Hoggen-Toggler[®] sampling apparatus allows collection of 8-inch-long by 1-inch inside-diameter (ID) continuous samples. Recovery efficiencies for samples in saturated or sandy soils are often reduced, or the samples are compromised, because of spillage of the soil from the device after extraction. To mitigate this problem, soil samples were compressed *in situ* with the penetrometer and Hoggen-Toggler[®] assembly to expel the pore water before extraction.

2.1.5 Equipment Decontamination Procedures

Prior to arriving onsite, and between each test location, CPT push rods were cleaned with the CPT steam-cleaning system (rod cleaner) as the rods were withdrawn from the ground. A vacuum system located beneath the CPT truck was used to recover cleaning water. Use of this system resulted in nearly 100 percent recovery of steam-cleaning rinseate from the rod cleaner. Rinseate was generated only as the rods moved past the cleaner, thereby minimizing liquid waste generation. Only potable water was used for decontamination. Rinseate was collected in 55-gallon drums provided by Seymour Johnson AFB. Filled 55-gallon drums were then emptied into an oil/water separator collection basin as directed by the Seymour Johnson AFB point of contact.

The soil samplers were disassembled upon sample collection and manually cleaned with a high-pressure steam/hot water wash. Contaminated soils (i.e., cuttings) were not generated during CPT field activities. Fuel, lubricants, and other similar substances were handled in a manner consistent with accepted safety procedures and standard operating practices. Well completion materials were not stored near or in areas that could be affected by these substances.

2.2 GEOPROBE[®] ACTIVITIES

Geoprobe[®]-related field work took place between April 10 and April 19, 1995, and consisted of drilling, soil sampling, and groundwater monitoring point installation. These

activities were performed according to the procedures described in the draft work plan (Parsons ES, 1995) and in the following sections.

The Geoprobe® system is a hydraulically powered percussion/probing machine used to advance sampling tools through unconsolidated soils. This system provides for the rapid collection of soil, soil gas, and groundwater samples at shallow depths while minimizing the generation of investigation-derived waste materials. Figure 2.3 is a diagram of the Geoprobe® system.

2.2.1 Soil Sampling Procedures

Parsons ES collected soil samples using the Geoprobe® system during the second phase of field activities. Soil sampling served four purposes:

- Validate the lithological data collected during CPT tests;
- Determine actual hydrocarbon concentrations in soils;
- Correlate the LIF direct readings to laboratory soil results; and
- Determine background soil geochemistry.

Parsons ES chose 12 locations (MW-1, MW-2, MW-4 through MW-6, MW-8 through MW-11, and SS-1 through SS-3) from which to collect soil samples (Table 2.1 and Figure 2.1). These samples, in combination with the LIF data, provide horizontal and vertical delineation of hydrocarbon contamination in site soils. Parsons ES collected several soil samples from each location to provide a vertical profile. Of these, 19 soil samples were submitted for laboratory analyses, including duplicates and quality assurance/quality control (QA/QC) samples. The field logs and analytical reports reference these soil samples with a monitoring well (MW) or soil sample (SS) prefix followed by a number. The soil sampling locations are shown on Figure 2.1.

Soil sampling was accomplished during this investigation using the Geoprobe® probe-drive soil sampler. The soil sampler serves as both the driving point and the sample collection device and is attached to the end of the leading end of the probe rods. The probe-drive samplers come in dimensions of approximately 0.5 inch [inside diameter (ID)] by 2 feet (length), and approximately 1 inch (ID) by 4 feet (length). The sampler is pushed or driven to the desired sampling depth, the drive point is retracted to open the sampling barrel, and the sampler is subsequently pushed into the undisturbed soils. The soil cores were retained within clear acetate liners inside the sampling barrel. The probe rods were then retracted, bringing the sampling device and liners containing the cores to the surface for inspection. Soil samples were extruded for logging, or the liners capped and submitted to the analytical laboratory for testing.

While at some locations, soil cores were collected continuously to the total depth of the probed hole, soil samples for laboratory analysis were obtained from each location at discrete depth intervals. The sampling depth(s) typically corresponded to the interval(s) with the highest LIF reading(s), the interval near the water table, or interval(s) where contamination was detected through photoionization detector (PID) screening. The Parsons ES field hydrogeologist observed all soil sampling and maintained descriptive

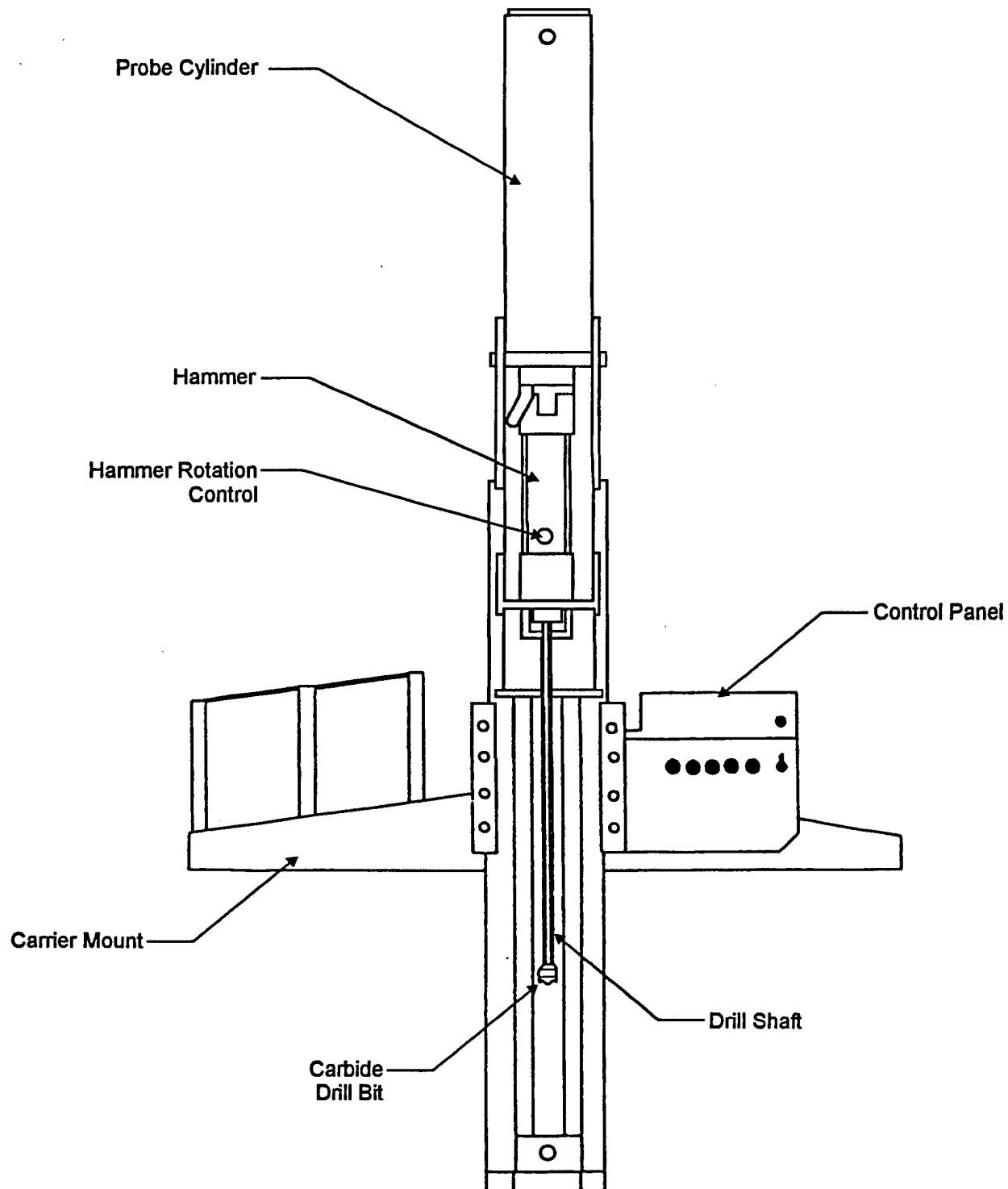


Figure 2.3

CROSS-SECTION OF GEOPROBE®

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notes of subsurface materials recovered. Observed soil classification types were compared to the soil classifications determined from CPT tests.

2.2.2 Equipment Decontamination Procedures

Prior to arriving onsite, Geoprobe® rods were cleaned with potable water using a steam-cleaning system. The soil samplers were disassembled after sample collection and manually cleaned with an Alconox® and potable water wash. The barrel was then rinsed with deionized water and reassembled with a new acetate liner. Rinseate was disposed of in the oil/water collection basin as directed by the Seymour Johnson AFB point of contact.

Contaminated soils (i.e., cuttings) were staged onsite during activities for later disposal in the Base soil bioremediation pile. Fuel, lubricants, and other similar substances were handled in a manner consistent with accepted safety procedures and standard operating practices. Well completion materials were not stored near or in areas that could be affected by these substances.

2.3 GROUNDWATER MONITORING POINT INSTALLATION

Twenty-three monitoring points were installed at 22 locations to provide hydrogeologic data required to characterize the shallow groundwater flow system at the former AGE fuel facility site. Locations were selected on the basis of lithologic and LIF data generated as a part of the CPT/LIF investigation. Four monitoring points were installed during the CPT/LIF investigation, 11 monitoring points were installed using the Geoprobe®, and eight monitoring points were installed using a hand auger. These monitoring point locations are identified as CPT-16 through CPT-19, and MW-2 through MW-19 (Figure 2.1). Two monitoring points (MW-12 and MW-12D) were installed in a cluster in the shallow aquifer in an area of suspected mobile LNAPL. Because a thick clay unit was consistently encountered at depths ranging from 11 to 18 feet below land surface (bls) and the depth to groundwater across the site ranged from 10 to 13 feet bls, MW-12 was the only location where multiple depth sampling points were installed. Table 2.1 presents well completion details for the monitoring points located on the site.

2.3.1 Materials Decontamination

Monitoring point construction materials were inspected by the field hydrogeologist and determined to be clean and acceptable prior to use. All monitoring point construction materials were factory sealed. Materials were inspected for possible external contamination before use. Materials that could not be cleaned to the satisfaction of the field hydrogeologist were not used.

2.3.2 Monitoring Point Screen and Casing

The Parsons ES field hydrogeologist considered the LIF data, soil core observations, and hydraulic characteristics of the stratum to select the appropriate screened interval for each monitoring point. Construction details were noted on a Monitoring Point Installation Record form (Appendix A) and are summarized in Table 2.1.

The four monitoring points installed using the SCAPS CPT rig (CPT-16 through CPT-19) consisted of a sacrificial steel tip attached to a 3.28-foot section of Schedule 40 PVC screen with 0.010-inch factory-slotted openings and a 0.5-inch ID. The screen was inserted through a hollow CPT pushrod with the sacrificial tip pushed into the end of the rod. As the pushrod was pressed into the ground, CPT pushrods and PVC casing were continuously attached until the desired depth was reached. Upon removal of the pushrods, a fully-cased monitoring point remained. Installation of a discrete sand pack was not possible with the CPT because soils immediately collapsed around the screens.

Monitoring points installed using the Geoprobe® were constructed of flush-threaded, PVC casing and screen with a 0.5-inch or 1.0-inch ID. Each monitoring point had a 5-foot screen length; screens were factory slotted with 0.020-inch openings. Monitoring points (MW-2 through MW-11) were installed in holes either probed or cored immediately prior to installation of monitoring points. Monitoring point MW-12D was installed inside the Geoprobe® rods and consisted of a 0.375-inch ID, 6-inch long stainless steel screen connected to a polyethylene tube. Like the CPT, monitoring points, a filter sand pack could not be installed around the Geoprobe®-installed monitoring point screens due to soil collapse.

Monitoring points MW-12 through MW-19 were installed in 3-inch-diameter boreholes that were advanced using a decontaminated stainless steel hand auger. Monitoring points MW-12 and MW-13 were completed using flush-threaded, 2-inch ID PVC casing and 0.010-inch slotted PVC screen. The 2-inch ID materials were used to allow mobile LNAPL thickness measurements with an oil/water interface probe. Monitoring points MW-14 through MW-19 were completed using flush-threaded, 1-inch ID PVC casing and 0.01-inch slotted PVC screen. Sand filter packs were installed in the annular space around the screens and bentonite seals were placed in the space above the sand packs.

All monitoring point casing sections were flush-threaded; glued joints were not used. Upon monitoring point completion to the proper termination depth, the monitoring point casing was cut slightly below land surface. The field hydrogeologist verified and recorded the hole depth and the lengths of all casing sections. All lengths and depths were measured to the nearest 0.1 foot. The casing was fitted with a plastic cap constructed of the same type of material as the casing. Barriers were then installed at each point until the point was either finished with a protective flush-mounted cover, above-grade cover, or, in the case of temporary points (Table 2.1), permanently abandoned. This information became part of the permanent field record for the site.

2.3.3 Sand Filter Pack and Annular Sealant

Where possible, a graded sand filter pack was placed around the screened interval from the bottom of the monitoring point annulus to approximately 2 feet above the top of the screen depending upon the borehole integrity. Locally purchased sand was used for the filter packs. Installation of filter packs was occasionally compromised by the collapse of the borehole walls. Therefore, some of the monitoring point screens are in contact with natural formation materials. This did not significantly affect monitoring point development or purging because of the sandy nature of the shallow aquifer material.

A filter pack seal of sodium bentonite pellets was placed above the sand pack in the monitoring points. The filter pack seal was approximately 0.5 to 2 feet thick and, where placed above the water table, was hydrated in place with potable water. On occasion, the collapse of formation materials into the borehole precluded the placement of a full 2-foot thickness of bentonite. In all monitoring points, the remaining annular seal to the ground surface also was completed with hydrated bentonite pellets. This was done because the water table was shallow enough to preclude the use of bentonite/cement grout.

2.3.4 Protective Covers

Monitoring points CPT-16, CPT-17, CPT-18, CPT-19, MW-2, MW-3, MW-4, MW-5, MW-6, MW-7, MW-8, MW-10, MW-11, MW-12, MW-12D, MW-13, MW-14, MW-15, MW-16, MW-17, MW-18, and MW-19 were completed as permanent monitoring points to enable future groundwater sampling at these locations (Table 2.1). Each permanent monitoring point was completed with an at-grade protective steel cover, except monitoring points MW-14 through MW-16 which were finished with above-grade protector pipes. The remaining points were constructed inside 8-inch-diameter vaults with flush-mounted steel covers. The protective covers were cemented in place using a concrete pad with dimensions of approximately 1.5-foot by 1.5-foot. All permanent monitoring points were completed with concrete pads that slope gently away from the protective casing to facilitate runoff during precipitation events.

2.4 MONITORING POINT DEVELOPMENT

Prior to sampling, the monitoring points were developed with a peristaltic pump. Monitoring point development typically removes sediment from inside the monitoring point casing and flushes fines, cuttings, and drilling fluids from the formation adjacent to the monitoring point screen. Use of the CPT and Geoprobe® systems to install monitoring points eliminates cuttings and drilling fluids. In monitoring points with PVC casing, the pump's suction tubing was regularly lowered to the bottom of the monitoring point so that fines were agitated and removed from the monitoring point with the development water. Development was continued until turbidity was minimized and the pH, temperature, specific conductivity, DO concentration, and redox potential of the groundwater had stabilized. All monitoring point development waters were collected and disposed of in the oil/water separator adjacent to the site as directed by the Seymour Johnson AFB point of contact.

2.5 GROUNDWATER SAMPLING

This section describes the procedures used for collecting groundwater quality samples. In order to maintain a high degree of quality control (QC) during this sampling event, the procedures described in the site work plan (Parsons ES, 1995) and summarized in the following sections were followed.

Groundwater sampling occurred April 12 through April 18, 1995 at the CPT- and Geoprobe®-installed monitoring points. The remaining monitoring points were sampled on July 10, 1995. Groundwater sampling forms were used to document the specific

details of the sampling event for each location. Groundwater samples were analyzed for the parameters listed in Table 2.2. Fixed-base sample analysis was performed by Evergreen Analytical, Inc., of Wheat Ridge, Colorado (Evergreen Analytical).

2.5.1 Groundwater Sampling Locations

Groundwater samples were collected from 19 monitoring points across the site. The monitoring points sampled were CPT-16, CPT-17, CPT-18, CPT-19, MW-3 through MW-8, MW-10, MW-11, MW-12D, and MW-14 through MW-19. Monitoring points were sampled using a peristaltic pump and dedicated polyethylene tubing. Two monitoring points did not produce sufficient groundwater volume for sampling, and two hand-augered monitoring points were installed into areas containing mobile LNAPL and therefore were not sampled for dissolved constituents. Locations of groundwater monitoring points are indicated on Figure 2.1.

2.5.2 Preparation for Sampling

All equipment used for sampling was assembled and properly cleaned and calibrated (if required) prior to arriving in the field. Special care was taken to prevent contamination of the groundwater and extracted samples through cross contamination from improperly cleaned equipment; therefore, water level indicators and sampling equipment were thoroughly cleaned before and after field use and between uses at different sampling locations. In addition, a clean pair of new, disposable gloves was worn each time a different well/point was sampled.

2.5.2.1 Equipment Decontamination

All portions of sampling and test equipment that contacted the samples were thoroughly cleaned before use. This equipment included the water level probe and cable, lifting line, test equipment for onsite use, and other equipment that contacted the samples or was placed downhole. The following cleaning protocol was used:

- Cleaned with potable water and phosphate-free laboratory detergent;
- Rinsed with potable water;
- Rinsed with distilled or deionized water;
- Rinsed with isopropanol;
- Air dried prior to use.

Any deviations from these procedures were documented in the field scientist's field notebook and on the groundwater sampling form.

TABLE 2.2
ANALYTICAL PROTOCOL FOR GROUNDWATER AND SOIL SAMPLES
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY SITE
SEYMOUR JOHNSON AFB, NORTH CAROLINA

MATRIX	METHOD	ANALYTICAL LABORATORY
WATER		
Total Iron	Colorimetric, Hach Method 8008	Field
Ferrous Iron (Fe +2)	Colorimetric, Hach Method 8146	Field
Manganese	Colorimetric, Hach Method 8034	Field
Sulfide	Colorimetric, Hach Method 8131	Field
Sulfate	Colorimetric, Hach Method 8051	Field
Sulfate	E300 or SW9056	Evergreen ^{a/}
Nitrate	E300 or SW9056	Evergreen
Nitrite	E300 or SW9056	Evergreen
Redox Potential	A2580B, direct reading meter	Field
Oxygen	Direct reading meter	Field
pH	Direct reading meter	Field
Conductivity	Direct reading meter	Field
Temperature	Direct reading meter	Field
Alkalinity (Carbonate [CO3-2] and Bicarbonate [HCO3-1])	Titrimetric, Hach Method 8221	Field
Carbon Dioxide	CHEMetrics Method 4500	Field
Chloride	Hach Model 8P	Field
Chloride	E300 or SW9056	Evergreen
Ammonia--Diss. Gas in Water	CHEMetrics Method 4500	Field
Alkalinity	310.1	Evergreen
Methane	RSKSOP175	Evergreen
Total Organic Carbon	EPA 415.1	Evergreen
Aromatic Hydrocarbons (Including Trimethylbenzenes and Tetramethylbenzene)	SW602 or SW624	Evergreen
Total Volatile Petroleum Hydrocarbons	SW8015, modified (Gasoline)	Evergreen
Total Extractable Petroleum Hydrocarbons	SW8015, modified (JP-4)	Evergreen
Semi-Volatile Organics	SW8270	Evergreen
Free Product	SW8020	Evergreen
Lead	SW6010	Evergreen
SOIL		
Total Organic Carbon	SW9060	Evergreen ^{b/}
Moisture	EPA 160.3	Evergreen
Aromatic Hydrocarbons	SW8020	Evergreen
Total Volatile and Extractable Hydrocarbons	SW8015, modified	Evergreen

a/ Evergreen Analytical, Inc. or Wheat Ridge, Colorado.

b/ Subcontracted by Evergreen to Huffman Laboratories of Golden, Colorado.

2.5.2.2 Equipment Calibration

As required, field analytical equipment were calibrated according to the manufacturer's specifications prior to field use. This applied to equipment used for onsite chemical measurements of DO, redox potential, pH, specific conductivity, and temperature.

2.5.2.3 Preparation of Location

The area around each monitoring point was cleared of foreign materials, such as brush, rocks, and debris prior to sampling. This prevented sampling equipment from inadvertently contacting debris around the monitoring point.

2.5.2.4 Water Level and Total Depth Measurements

Prior to removing any water from the monitoring point, the static water level was measured. An electric water level probe was used to measure the depth to groundwater to the nearest 0.01 foot below the datum. An oil/water interface probe capable of measuring the depth to both petroleum product (if present) and water was used in the 2-inch diameter monitoring points. After measuring the static water level, the water level probe was lowered to the bottom of the monitoring point for measurement of total depth (recorded to the nearest 0.01 foot). Based on these measurements, the volume of water to be purged from the wells was estimated.

Static groundwater levels also were measured on April 26, 1995, May 18, 1995, and July 19, 1995 at all monitoring points to obtain snapshots of the water table surface at the site.

2.5.3 Well Purging and Sample Collection

Well purging consisted of removing at least three times the calculated casing volume with a peristaltic pump prior to sample collection. All purge water was collected and disposed of in the adjacent oil/water separator as directed by the Seymour Johnson AFB point of contact.

Within 24 hours of the purge event, a peristaltic pump with dedicated silicon and HDPE tubing was used to extract groundwater samples from the well. A disposable bailer was used to collect a mobile LNAPL sample from MW-13. The samples were transferred directly into the appropriate sample containers. The water was carefully poured down the inner walls of the sample bottle to minimize aeration of the sample. Sample bottles for BTEX, trimethylbenzenes (TMB), and dissolved gas analyses were filled so that there was no headspace or air bubbles within the container. Excess water collected during sampling was placed into containers used for monitoring point purge waters. After purging and sampling each monitoring point, Parsons ES transported containers to the Seymour Johnson AFB designated oil/water separator collection basin location for disposal.

2.5.4 Onsite Chemical Parameter Measurement

Many chemical parameters in groundwater can change significantly within a short time following sample acquisition. To avoid this occurrence, these parameters were measured in the field during sample collection. The following procedure was used during groundwater sampling for all direct-reading instruments (e.g., DO, redox, pH, temperature, and electric conductivity). An Erlenmeyer flask was installed downstream from the peristaltic pump to form a flow-through chamber for the sampling probes. The extracted groundwater flowed over the probes while immersed in the Erlenmeyer flask. This effectively produces a flow-through cell that minimizes aeration of the sample. As a result, a continuous measurement from the direct-reading instruments was possible. Pumping continued until the readings stabilized. The stabilized reading was recorded.

2.5.4.1 Dissolved Oxygen Measurements

DO measurements were taken using a YSI® model 55 hand-held DO meter using the above-described procedures. DO concentrations were determined while the probe was immersed in an Erlenmeyer flask. This effectively minimized aeration of the sample. DO concentrations were recorded after the readings stabilized. In all cases, the lowest DO concentration was recorded.

2.5.4.2 Reduction/Oxidation Potential Measurements

Redox potential measurements were taken using an Orion® model 290A redox potential meter. Redox potential measurements were recorded after the readings stabilized and generally represent the lowest redox potential observed.

2.5.4.3 Temperature, pH, and Electrical and Conductance

Temperature, pH and electrical conductance were determined with an Orion® model 290A meter. These parameters were recorded after the readings stabilized and generally represent the average reading after stabilization.

2.5.4.4 Hach® and CHEMetrics® Field Chemistry Measurements

An onsite laboratory staffed by Parsons ES personnel was used to analyze for several indicator parameters in groundwater samples collected from existing monitoring wells and newly installed monitoring points. A Hach® DR/700 colorimeter was used to measure ferrous iron (Fe^{2+}), total iron (Fe), nitrate (NO_3^-), nitrite (NO_2^-), sulfate (SO_4^{2-}), manganese (Mn^{2+}), and sulfide (S^{2-}). Titrations using Hach® reagents were conducted to measure alkalinity [as milligrams per liter (mg/L) calcium carbonate (CaCO_3)] and chloride (Cl^-). CHEMetrics® color tests were used to measure ammonia (NH_3) and carbon dioxide (CO_2). These analyses were completed for each groundwater sample after all sample containers had been filled. The sample to be analyzed was poured into a clean glass container, capped, and transported to the Parsons ES on-Base laboratory for analysis. Care was taken to avoid any headspace in the sample container, which could influence the

concentration of reduced species. The field holding time for each sample did not exceed one hour. Care was taken to minimize sample temperature changes and exposure to sunlight. Concentrations of these indicator parameters were not measured in soil samples.

2.5.5 Sample Handling

Evergreen Analytical provided sample containers, pre-preserved when appropriate, with appropriate sample lids. The sample containers were filled as described in Section 2.5.3, and the container lids were tightly closed. The sample label was firmly attached to the container side, and the following information was legibly and indelibly written on the label:

- Facility name;
- Sample identification;
- Sample type (i.e., groundwater);
- Sampling date;
- Sampling time;
- Preservatives added; and,
- Sample collector's initials.

The samples were sealed, labeled, and placed in an iced cooler. Then, coolers were packaged for transport to Evergreen Analytical and hand-delivered to the Federal Express® pickup location for next-day priority delivery. The following packaging and labeling procedures were followed:

- Sample was packaged to prevent leakage or vaporization from its container;
- Shipping container was labeled with
 - Sample collector's name, address, and telephone number;
 - Laboratory's name, address, and telephone number; and
 - Date of shipment.

Chain-of-custody forms were placed inside the coolers. Coolers were sealed with packing tape and the integrity of the coolers seals were monitored by placing chain-of-custody seals across at least 2 sides of the cooler lid.

2.6 SURVEYING

The locations and elevations of the monitoring points were surveyed by Benton and Associates personnel on April 26, 1995. The horizontal locations were measured relative to established site coordinates. Horizontal coordinates were measured to the nearest 1 foot. Vertical location of the monitoring point top-of-casing elevations and adjacent ground surface was measured relative to a benchmark established at the site. Survey data are presented in Table 2.1.

SECTION 3

PHYSICAL CHARACTERISTICS OF THE STUDY AREA

This section incorporates data collected from other sites at Seymour Johnson AFB during investigations by Law Environmental, Inc. (1989 and 1992) and Geophex, Inc. (1989) with data from more recent investigations conducted by Parsons ES. The investigative techniques used by Parsons ES to determine the site-specific physical characteristics at the former AGE fueling facility are discussed in Section 2.

3.1 SURFACE FEATURES

3.1.1 Topography and Surface Water Hydrology

Seymour Johnson AFB exhibits little topographic variation. The Base is nearly level, with steeper drops toward the floodplains of the Neuse River and its tributary, Stoney Creek. The former AGE fueling area is located at approximately 90 feet above mean sea level (msl). Any significant elevation changes at Seymour Johnson AFB and the surrounding areas are mostly the result of erosional activity and/or stream channel development.

The primary surface water drainage feature at Seymour Johnson AFB is the Neuse River, which forms the southwestern boundary of the Base. Stoney Creek, a major tributary to the Neuse River, forms the northwestern Base boundary (Figure 1.2). Storm water is drained from the Base to either Stoney Creek or the Neuse River through a system of surface ditches and subsurface piping. Many of the surface drainageways are in direct communication with groundwater in the surficial aquifer and act as groundwater discharge boundaries. In the vicinity of the AGE fueling facility, the nearest surface water body that could serve as a potential point of discharge is a drainage creek approximately 850 feet downgradient from the site. As discussed in Section 3.1.2, there are several manmade features at or near the site that influence surface water runoff.

3.1.2 Manmade Features

Land surface cover at the former AGE fueling facility site and adjacent areas consists of concrete and asphalt driveways and parking areas, grassy landscaped areas, buildings, and other impervious structures. The majority of the precipitation that falls on the base either infiltrates into the subsurface or is captured by the storm water drainage system. Numerous subsurface utilities are located in the vicinity of the former AGE fueling facility site. Subsurface utilities in the vicinity of the site are expected to have little influence on groundwater flow because the water table ranges from about 10 to 14 feet bls, which is below the typical range of utility trench depths. Utility trenches may affect subsurface infiltration and flow of water and contaminants in the vadose zone.

The closest storm water drainage feature is a ditch approximately 100 feet to the north of the site. The ditch runs to the east and is approximately 5 feet in depth (i.e. does not intersect the groundwater table). Water was observed in the ditch only during significant rainfall events. The aqueous fire fighting foam (AFFF) lagoon, approximately 200 feet to the southeast of the site, is a synthetically-lined collection basin for fire fighting foam overflow. The AFFF lagoon is approximately 10 feet deep and does not appear to interact with groundwater.

3.2 REGIONAL GEOLOGY AND HYDROGEOLOGY

Seymour Johnson AFB is located in the middle region of the Atlantic Coastal Plain Physiographic Province, a wide wedge-shaped belt of Cretaceous to Recent sedimentary deposits (Foster, 1950). The western boundary of the middle Coastal Plain is formed by the Coats scarp at an elevation of 275 feet msl. In the middle Coastal Plain, land slopes gently to the east to the Surry scarp (at 94 feet msl) where the lower region of the Coastal Plain begins. Seymour Johnson AFB is located approximately 25 miles east of the Fall Line, which marks the boundary between the Coastal Plain and the Piedmont physiographic provinces.

In the area of the Base, the geology consists of unconsolidated sediments unconformably overlying pre-Cretaceous bedrock (Research Triangle Institute [RTI], 1988). The surficial deposits consist of the Goldsboro Sand and the Sunderland Formation. The Holocene-aged Goldsboro Sand is made up of a fairly uniform medium-grained sand with some sandy clay and clay lenses. The Pliocene-aged Sunderland Formation consists of poorly sorted sediments ranging from sandy clay and clay to gravel deposits. Beneath a thin surficial veneer of Quaternary and Tertiary sediments, the Cretaceous Black Creek and the Cape Fear Formations underlie the area around Seymour Johnson AFB. The Black Creek Formation is made up of dark gray to black, thinly laminated montmorillonite clays interbedded with glauconitic sand lenses. At the Base, the Black Creek Formation is reported by local well drillers to be greater than 50 feet thick. The Cape Fear Formation consists of light-colored, poorly sorted quartz sands and montmorillonitic feldspathic clays. The formation contains mica, lignite, and iron sulfides that are found as concretions, disseminated grains, or as a replacement mineral in wood fragments.

The uppermost hydrogeologic unit at Seymour Johnson AFB consists of an unconfined aquifer within the surficial deposits. Groundwater flow directions within the surficial unconfined aquifer are controlled by topography on a local scale. The overall direction of flow in the surficial aquifer is generally to the west and northwest toward the Neuse River and Stoney Creek.

The surficial unconfined aquifer is underlain by a series of interbedded sands and clays making up the regional, confined aquifer units of the Black Creek aquifer. At Seymour Johnson AFB, the productive zones of the Black Creek aquifer are found below 10 feet msl (Law Environmental, 1992), which is approximately 90 feet bls at the Base. Beneath the Black Creek aquifer, the Cape Fear Formation contains the third major aquifer system in the area. Many production wells tap both the Black Creek and the Cape Fear aquifers.

Depth to groundwater within the surficial aquifer ranges from approximately 1 foot bls near the Neuse River and its tributaries to about 15 feet bls in the central portion of Seymour Johnson AFB. The hydraulic conductivity of the surficial aquifer at Seymour Johnson AFB has been reported to range from 5 to 40 feet per day (ft/day). The hydraulic conductivity of the Black Creek aquifer at Seymour Johnson AFB has been reported to be approximately 1.45 ft/day (Law Environmental, 1992).

3.3 SITE GEOLOGY AND HYDROGEOLOGY

Characterization of the vadose zone and shallow unconfined aquifer at the former AGE fueling facility site was one of the major objectives of the investigations by Parsons ES. As part of field activities, 10 locations were investigated using CPT in conjunction with LIF to examine site lithology and hydrocarbon contamination. Continuous soil core sampling was performed at 13 locations using the Geoprobe® and at 2 locations using a hand auger to further define the lithology and vadose zone contamination at the site.

3.3.1 Lithology and Stratigraphic Relationships

The surficial sediments underlying the former AGE fueling facility site consist of naturally deposited alluvial silts, clays, and sands that overlie the clay of the Black Creek Formation. The upper, unconfined aquifer occurs within these surficial sediments, and the Black Creek Formation's upper clay forms the base of the surficial aquifer. The thickness of the surficial sediments beneath the site ranges from about 10 to 20 feet. At the former AGE fueling facility site, the surficial sediments consist of 5 to 10 feet of silty to sandy clay underlain by 5 to 10 feet of sand that coarsens with depth. The stratigraphic relationships at the site are illustrated by hydrogeologic sections A-A', B-B', and C-C'. Figure 3.1 shows the location of these sections, which are presented on Figures 3.2, 3.3, and 3.4.

In general, the surficial stratigraphy of the site can be characterized as a series of three distinct sedimentary units overlying the upper clay of the Black Creek Formation. The upper surficial unit is comprised of dark-gray to light-brown silty sand that sometimes contains fill material, topsoil, and/or organic matter. Light-gray silty to sandy clay with orange to red mottling underlies the upper surficial unit. A light-gray to orange-brown, slightly silty, medium to coarse sand is the third unit encountered above the clay of the Black Creek Formation. It is within this sand unit that the unconfined surficial aquifer is found at the site. The upper clay strata of the Black Creek Formation acts as the basal confining unit for the surficial aquifer at the former AGE fueling facility site.

3.3.2 Groundwater Hydraulics

3.3.2.1 Groundwater Flow Direction and Gradient

Groundwater elevations within the shallow aquifer range from approximately 85 to 88 feet msl. Figure 3.5 shows a map of the water table surface of the unconfined aquifer at the site, based on groundwater elevations measured in monitoring points on July 19,

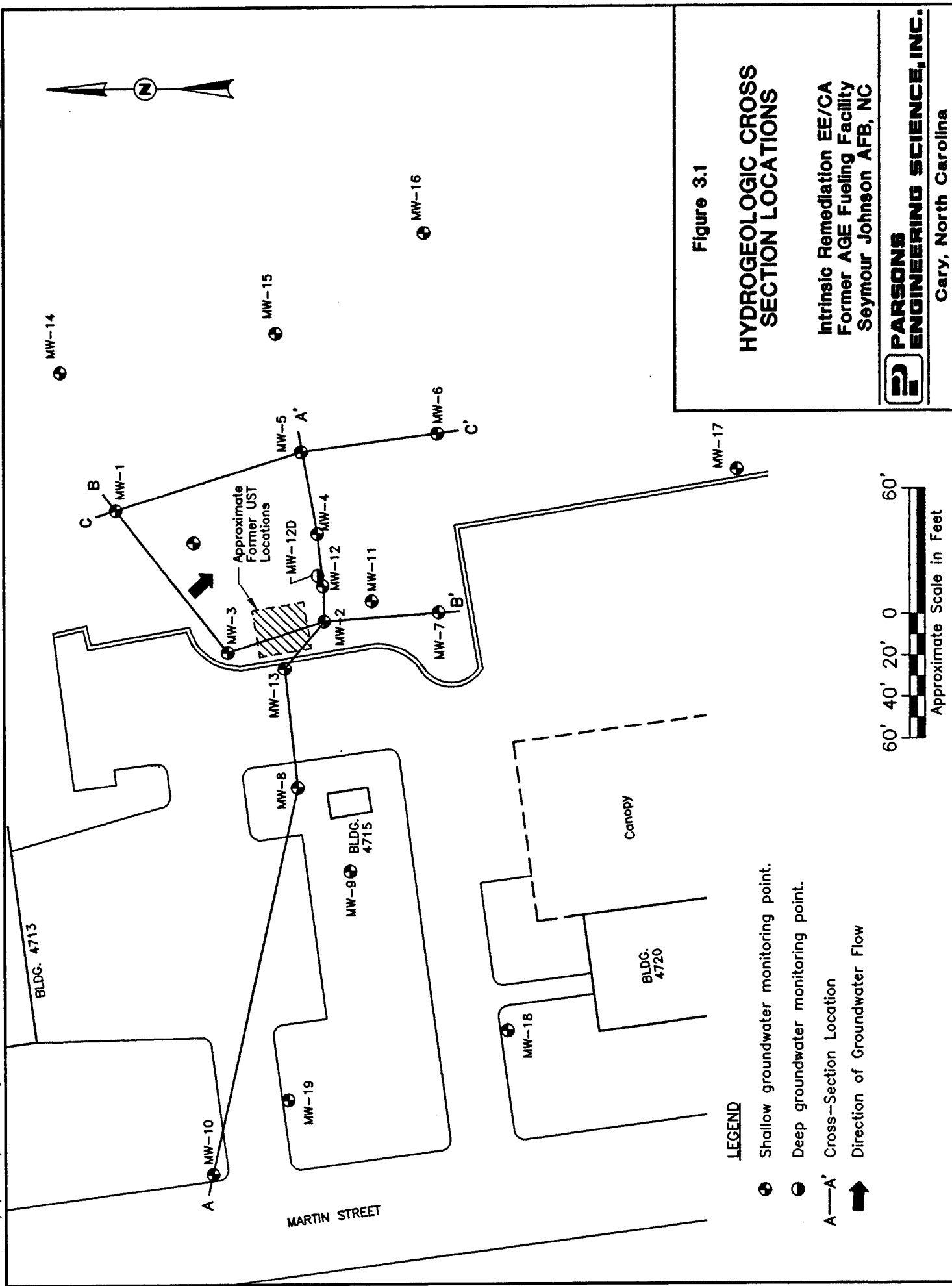


Figure 3.1

HYDROGEOLOGIC CROSS SECTION LOCATIONS

Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC

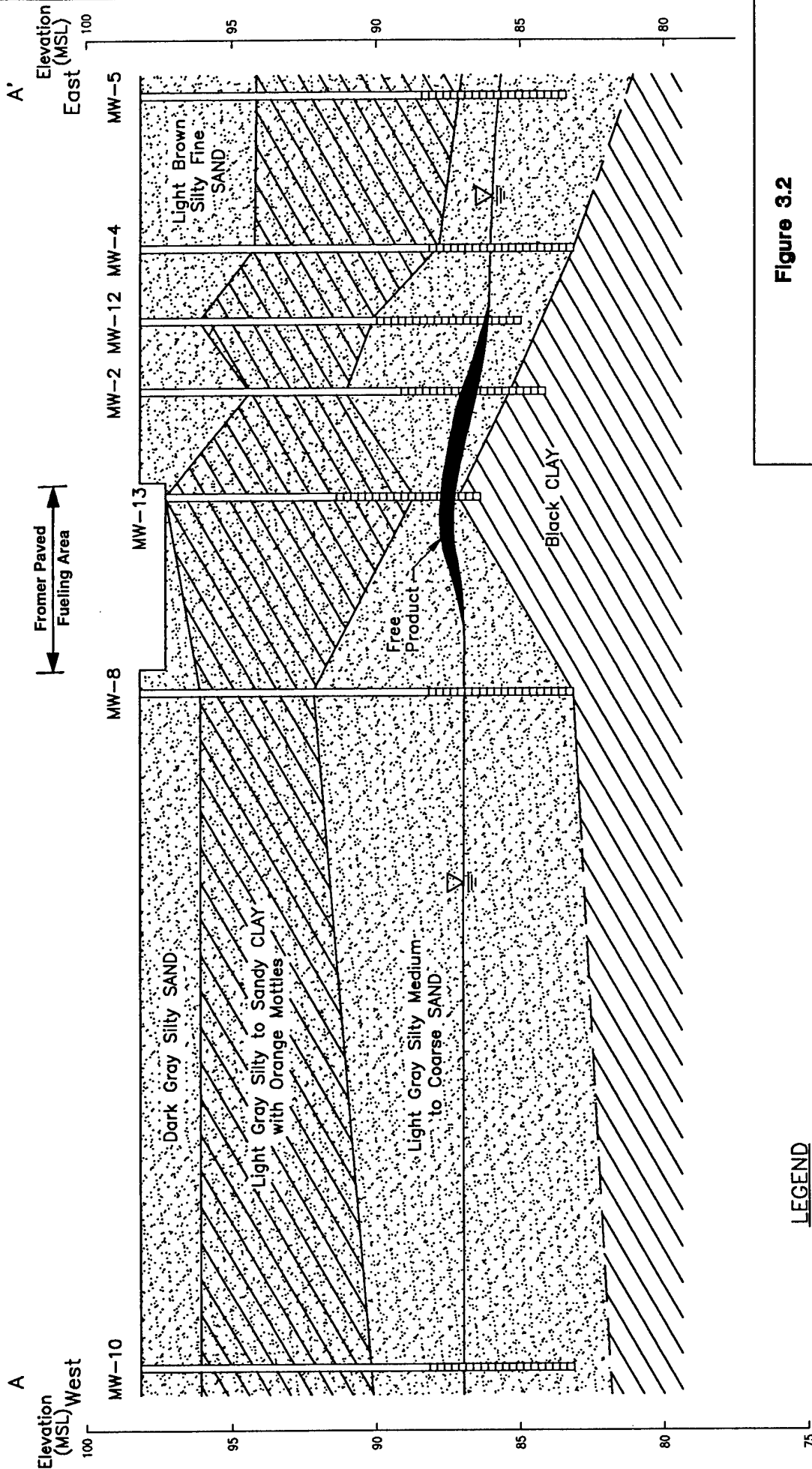


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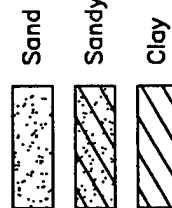
Cary, North Carolina

LEGEND

- Shallow groundwater monitoring point.
- Deep groundwater monitoring point.
- A—A' Cross-Section Location
- ➔ Direction of Groundwater Flow



LEGEND



Monitoring point screen interval.

Water table.

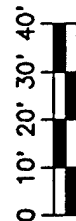


Figure 3.2

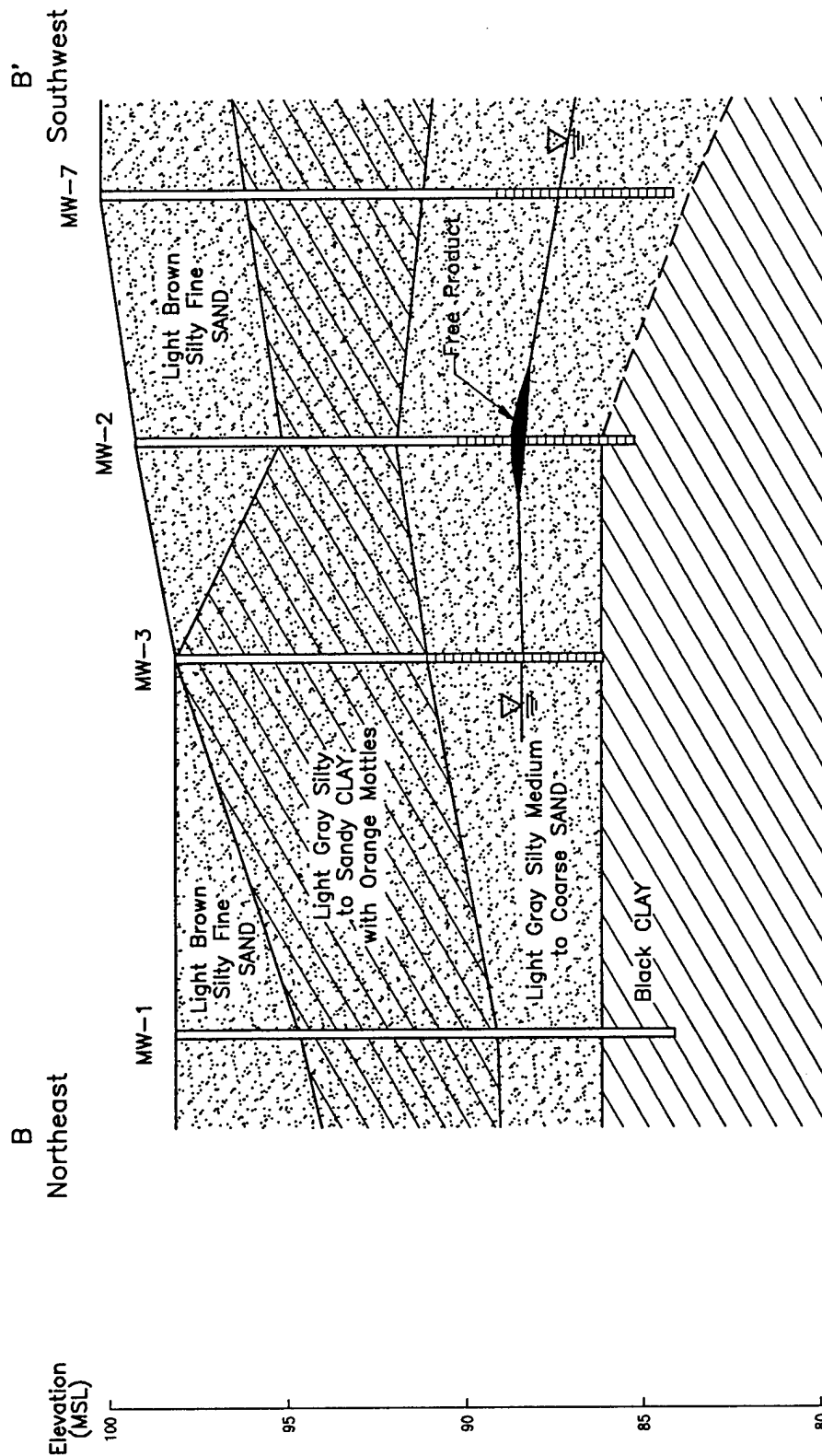
HYDROGEOLOGIC CROSS-SECTION A-A'

Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC

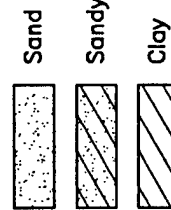


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ENGINEERING SCIENCE, INC.**

Cary, North Carolina



LEGEND



Monitoring point screen interval.

Water table.

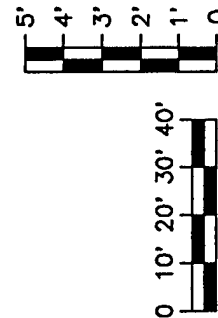


Figure 3.3

HYDROGEOLOGIC CROSS-SECTION B-B'

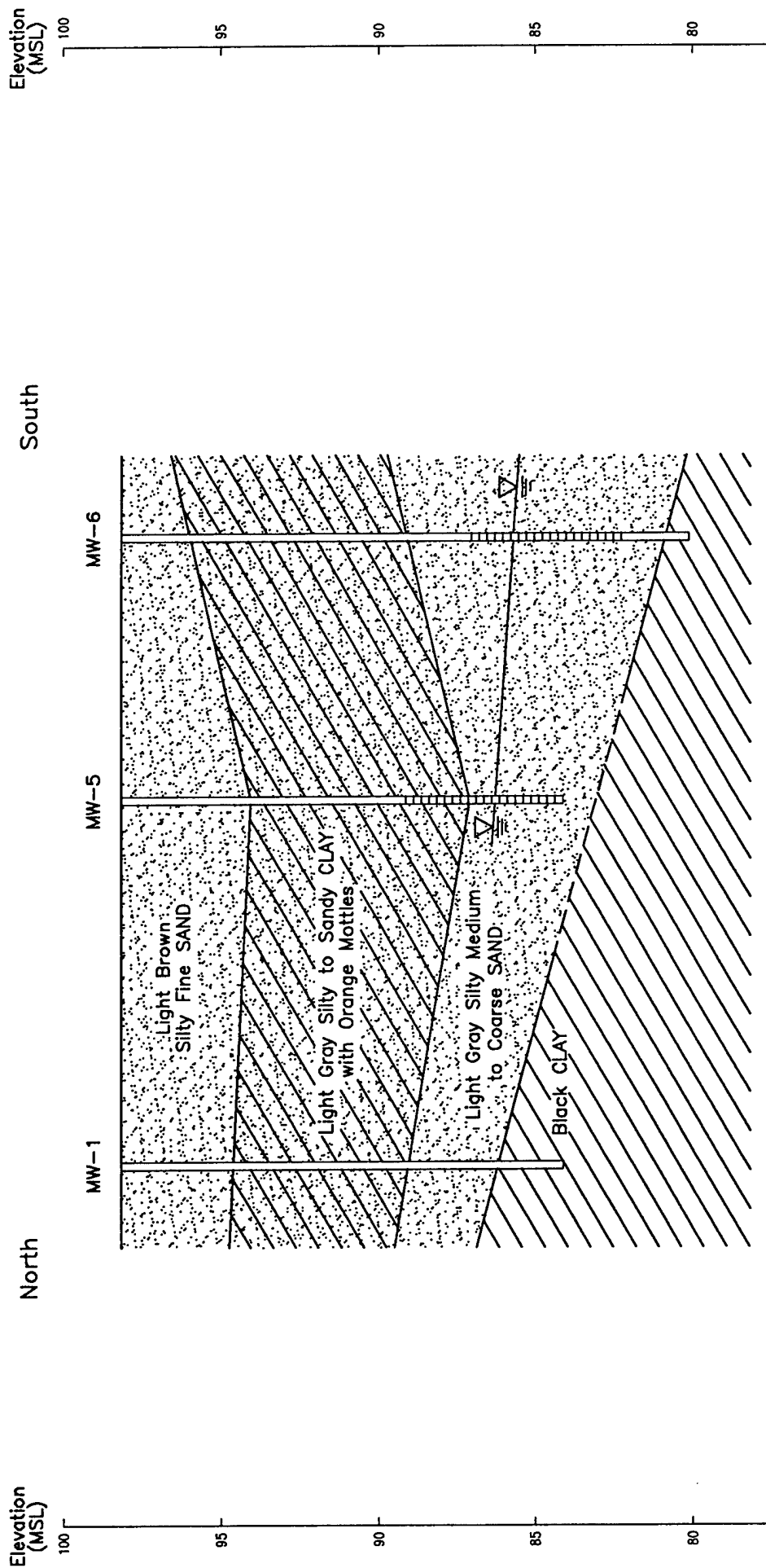
Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC



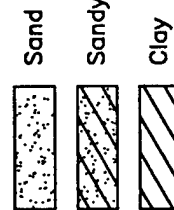
**PARSONS
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Cary, North Carolina

C North C' South



LEGEND



Monitoring point screen interval.

Water table.

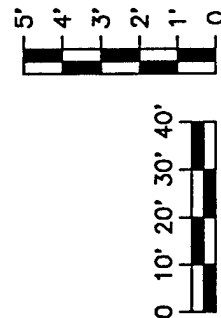


Figure 3.4

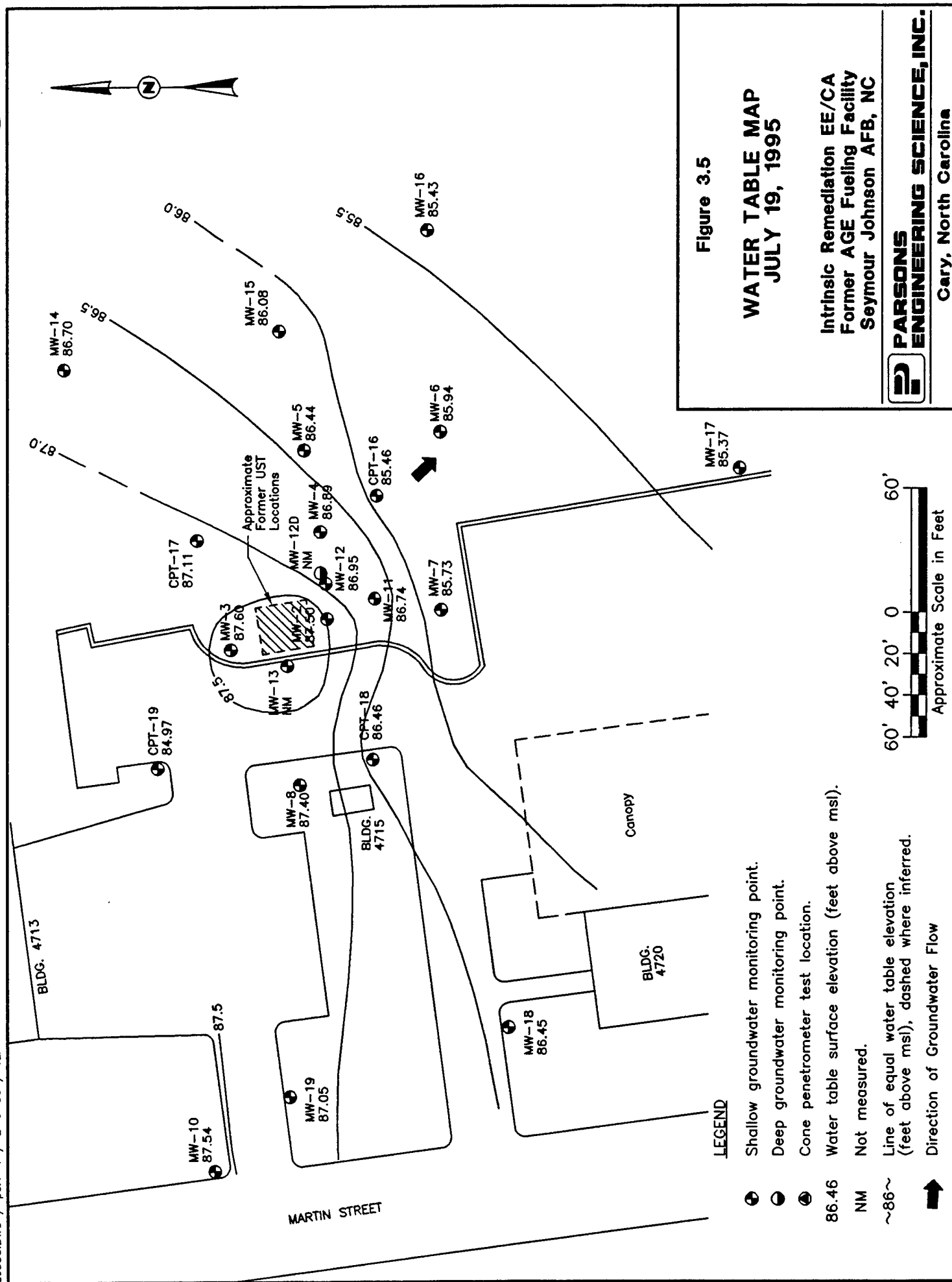
HYDROGEOLOGIC CROSS-SECTION C-C'

Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC



PARSONS
ENGINEERING SCIENCE, INC.

Cary, North Carolina



1995 (Table 3.1). The groundwater elevation observed in CPT-19 was anomalous and was not used in construction of the water table surface map.

On the basis of groundwater elevations and contaminant concentrations detected in site monitoring points, groundwater in the unconfined aquifer at the site may flow in several directions from the area of the contaminant source (Figure 3.5). The primary direction of site groundwater flow is toward the southeast. However, based on groundwater elevations in monitoring points at the perimeter of the site, groundwater flows from a slight mound in the immediate area of the contaminant source (the former UST area) not only to the southeast, but also to the northeast and to the south-southwest.

The overall horizontal hydraulic gradient at the former AGE fueling facility toward the southeast (from MW-10 to MW-17) was 0.005 foot per foot (ft/ft); however, in the source area the hydraulic gradient toward the southeast was 0.011 ft/ft (from MW-3 to MW-6). Some of the observed groundwater elevations and directions of flow may result from differential recharge effects in the area. Impervious areas and adjacent uncovered areas can cause local anomalies in a regional groundwater flow pattern. Groundwater mounding in the source area may be due to higher-permeability material used to backfill the UST excavation.

3.3.2.2 Hydraulic Conductivity

Hydraulic conductivity (K) in the surficial unconfined aquifer has been characterized at several sites at Seymour Johnson AFB using several different test methods. Data from aquifer testing performed at other sites at the Base are fairly consistent and are considered to be representative of the characteristics of the surficial unconfined aquifer at the former AGE fueling facility site. The hydraulic conductivity at one IRP site approximately 800 feet to the southeast of this site was determined using slug testing and was estimated using grain size distribution analysis. The K range determined using slug testing was 2.4×10^{-3} to 1.2×10^{-2} centimeters per second (cm/sec) (6.8 to 34 ft/day) (Law Environmental, 1989). Using grain-size distribution data from Law (1989), the estimated K for the surficial aquifer is approximately 1.5×10^{-2} cm/sec (42.5 ft/day). At two other sites at the Base, the hydraulic conductivity estimates using aquifer pump test data ranged from 8.8×10^{-4} to 1.3×10^{-3} cm/sec (2.5 to 4 ft/day) (Law Environmental, 1992). Based on these data, hydraulic conductivity for the surficial unconfined aquifer at the Base ranges from 2.5 to 42.5 ft/day. The average hydraulic conductivity for the surficial unconfined aquifer as determined from available data is approximately 15 ft/day or 0.0053 cm/sec.

3.3.2.3 Advective Groundwater Velocity

Darcy's Law was used to calculate the average advective groundwater flow velocity in the surficial aquifer at the former AGE fueling facility site. The average groundwater flow velocity toward the southeast, the primary direction of flow, is approximately 0.25 ft/day, or 91 feet per year (ft/yr). The groundwater flow velocity was calculated using a hydraulic conductivity of 15 ft/day, an estimated effective porosity of 0.3, and the observed site-wide hydraulic gradient of 0.005 ft/ft.

TABLE 3.1
WATER LEVEL ELEVATION DATA FROM MONITORING POINTS
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY
SEYMOUR JOHNSON AFB, NORTH CAROLINA

Sample Location ^{a/}	Sampling Date	Datum Elevation ^{b/} (ft msl) ^{c/}	Monitoring Point Depth (ft btoc) ^{d/}	Product Thickness (ft)	Water Depth (ft btoc)	Water Table Elevation (ft msl)
CPT-16	4/26/95	98.76	14.45	0.00	12.58	86.18
	5/18/95	98.76	14.45	0.00	12.86	85.90
	7/19/95	98.76	14.45	NM ^{e/}	12.30	86.46
CPT-17	4/26/95	97.37	14.62	0.00	10.73	86.64
	5/18/95	97.37	14.62	0.00	10.90	86.47
	7/19/95	97.37	14.62	NM	10.26	87.11
CPT-18	4/26/95	98.11	14.55	0.00	11.39	86.72
	5/18/95	98.11	14.55	0.00	11.55	86.56
	7/19/95	98.11	14.55	NM	11.65	86.46
CPT-19	4/26/95	96.86	14.80	0.00	11.78	85.08
	5/18/95	96.86	14.80	0.00	11.85	85.01
	7/19/95	96.86	14.80	NM	11.89	84.97
MW-2	4/26/95	97.76	11.55	NM	10.72	87.04
	5/18/95	97.76	11.55	NM	9.98	87.78
	7/19/95	97.76	11.55	NM	10.26	87.50
MW-3	4/26/95	96.78	11.30	0.00	9.69	87.09
	5/18/95	96.78	11.30	0.00	9.86	86.92
	7/19/95	96.78	11.30	NM	9.18	87.60
MW-4	4/26/95	98.44	14.43	0.00	11.93	86.51
	5/18/95	98.44	14.43	0.00	12.23	86.21
	7/19/95	98.44	14.43	NM	11.55	86.89
MW-5	4/26/95	97.93	13.52	0.00	11.80	86.13
	5/18/95	97.93	13.52	0.00	12.07	85.86
	7/19/95	97.93	13.52	NM	11.49	86.44
MW-6	4/26/95	98.22	15.80	0.00	12.40	85.82
	5/18/95	98.22	15.80	0.00	12.67	85.55
	7/19/95	98.22	15.80	NM	12.28	85.94
MW-7	4/26/95	98.64	15.10	0.00	12.64	86.00
	5/18/95	98.64	15.10	0.00	12.91	85.73
	7/19/95	98.64	15.10	NM	12.36	86.28
MW-8	4/26/95	97.98	12.71	0.00	11.09	86.89
	5/18/95	97.98	12.71	0.00	11.16	86.82
	7/19/95	97.98	12.71	NM	10.58	87.40
MW-9	4/26/95	99.23	9.56	0.00	DRY	DRY
	5/18/95	99.23	9.56	0.00	DRY	DRY
	7/19/95	99.23	9.56	NM	DRY	DRY
MW-10	4/26/95	98.08	12.11	0.00	11.03	87.05
	5/18/95	98.08	12.11	0.00	11.03	87.05
	7/19/95	98.08	12.11	NM	10.54	87.54

TABLE 3.1 (continued)
WATER LEVEL ELEVATION DATA FROM MONITORING POINTS
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY
SEYMOUR JOHNSON AFB, NORTH CAROLINA

Sample Location ^{a/}	Sampling Date	Datum Elevation ^{b/} (ft msl) ^{c/}	Monitoring Point Depth (ft btoc) ^{d/}	Product Thickness (ft)	Water Depth (ft btoc)	Water Table Elevation (ft msl)
MW-11	4/26/95	98.52	15.73	0.00	12.13	86.39
	5/18/95	98.52	15.73	0.00	12.38	86.14
	7/19/95	98.52	15.73	NM	11.78	86.74
MW-12	4/26/95	98.57	12.82	SHEEN	12.20	86.37
	5/18/95	98.57	12.82	0.01	12.30	86.28
	7/19/95	98.57	12.82	NM	11.62	86.95
MW-12D	4/26/95	NA ^{h/}	17.00	0.00	NM	NA ^{h/}
	5/18/95	NA ^{h/}	17.00	0.00	NM	NA
	7/19/95	NA ^{h/}	17.00	NM	NM	NA
MW-13	4/26/95	96.64	11.25	0.53	10.43	86.60
	5/18/95	96.64	11.25	1.19	10.44	87.07
	7/19/95	96.64	11.25	NM	NM	NA
MW-14	7/19/95	98.99	10.50	NM	12.29	86.70
MW-15	7/19/95	99.66	13.00	NM	13.58	86.08
MW-16	7/19/95	98.08	12.00	NM	12.65	85.43
MW-17	7/19/95	97.38	15.00	NM	12.01	85.37
MW-18	7/19/95	98.34	15.00	NM	11.89	86.45
MW-19	7/19/95	98.13	14.00	NM	11.08	87.05

^{a/} See Figure 2.1 for sample locations.

^{b/} Datum elevation refers to top of casing.

^{c/} ft msl = feet above mean sea level.

^{d/} ft btoc = feet below top of casing.

^{e/} NM = not measured (MW-2 diameter too small for oil/water interface probe).

^{f/} NA = not applicable.

3.3.3 Preferential Flow Paths

No preferential contaminant migration pathways due to artificial (man-made) conduits were identified at the site. Although numerous subsurface utilities underlie some portions of the area under investigation, no effects on contaminant distribution or groundwater flow pattern were noted. The influence of differential recharge to the surficial aquifer on the water table surface is seen by anomalous groundwater elevations in several of the monitoring points. The influence of differential recharge on the migration of contaminants in shallow groundwater at the site is discussed in Section 4.

3.3.4 Groundwater Use

Groundwater from the surficial unconfined aquifer at Seymour Johnson AFB is not extracted for potable water supply. There are no known active drinking water supply wells on or near the Base. Potable water supply for the Base and the surrounding area is obtained from the City of Goldsboro municipal water system. Regionally, groundwater for potable supply is withdrawn from aquifers of the lower Black Creek Formation and the Cape Fear Formation. Wells drawing from these aquifers in the Goldsboro area are generally greater than 80 feet deep, below the upper clay of the Black Creek Formation.

3.4 CLIMATOLOGICAL CHARACTERISTICS

The Goldsboro, North Carolina area has a temperate climate resulting from its latitude and its close geographic proximity to the Atlantic Ocean. Spring and fall are characterized by a succession of warm and cold periods associated with storm activity. Summers and winters are characterized as humid, making the winters more penetrating and the summers more sweltering than experienced in the drier climates of the central United States (Gale Research Co., 1985). The mean annual precipitation for the base is approximately 50 inches per year (North Carolina State University [NCSU], 1988). Mean daily temperatures range from 41.5 to 79.7 degrees Fahrenheit (°F) (NCSU, 1988).

SECTION 4

NATURE AND EXTENT OF CONTAMINATION AND SOIL AND GROUNDWATER GEOCHEMISTRY

4.1 SOURCE OF CONTAMINATION

The former AGE fueling facility at Building 4715 is no longer in operation. A fuel release at the facility was first suspected during the UST closure in 1994, when organic vapors were detected in soil samples screened using a PID (Seymour Johnson AFB, 1995). The exact date, volume, and origin of the release within the UST system is unknown. Three USTs were used at the facility to store JP-4, gasoline, and diesel fuel. Due to the presence of three USTs, subsurface fuel lines, pumps, and fueling hydrants that were part of the UST system, it is likely that the subsurface fuel contamination now present is attributable to several releases over time. Based on the distribution of contamination, leaks along the subsurface fuel pipelines and at the fuel pumps are probably the major sources of releases, with minor contributions from surface spills related to fueling and maintenance operations.

The nature and extent of site contamination was characterized during the field work conducted for this EE/CA, as described in the following subsections. Full-scale remedial activities have not yet been initiated at the site. Free product is bailed manually from well MW-13 on a weekly basis as per the requirements of the North Carolina Department of Environmental Management (DEM). As evident from the LIF data, analytical results of soil samples, and the presence of mobile LNAPL in several groundwater monitoring points, areas of significant free product and/or soil contamination exist at the site. These areas are acting as continuing sources for groundwater contamination.

4.2 MOBILE LNAPL CONTAMINATION

Mobile LNAPL is defined as the LNAPL that is free to flow in the aquifer and that will flow from the aquifer matrix into a well under the influence of gravity. The approximate extent of mobile LNAPL observed at the former AGE fueling facility is shown in Figure 4.1. Mobile LNAPL was observed in monitoring points MW-12 and MW-13 during this investigation (see Table 3.1). The measured thickness of the mobile LNAPL in MW-13 varied from 0.53 foot to 1.95 feet during this investigation. The LIF intensity measured at CPT-2 and CPT-6 (Table 4.1) suggests that LNAPL may also be present in the adjacent monitoring points, MW-2 and MW-4. Product thickness could not be measured in MW-2 or MW-4 because the ID of the monitoring points is too narrow to admit an oil/water interface probe. A small amount of LNAPL was recovered from monitoring point MW-2; however, the recovered volume was not sufficient to sample for total BTEX.

A sample of mobile LNAPL was collected from MW-13 and analyzed by United States Environmental Protection Agency (USEPA) Method SW8020 (See Table 4.2).

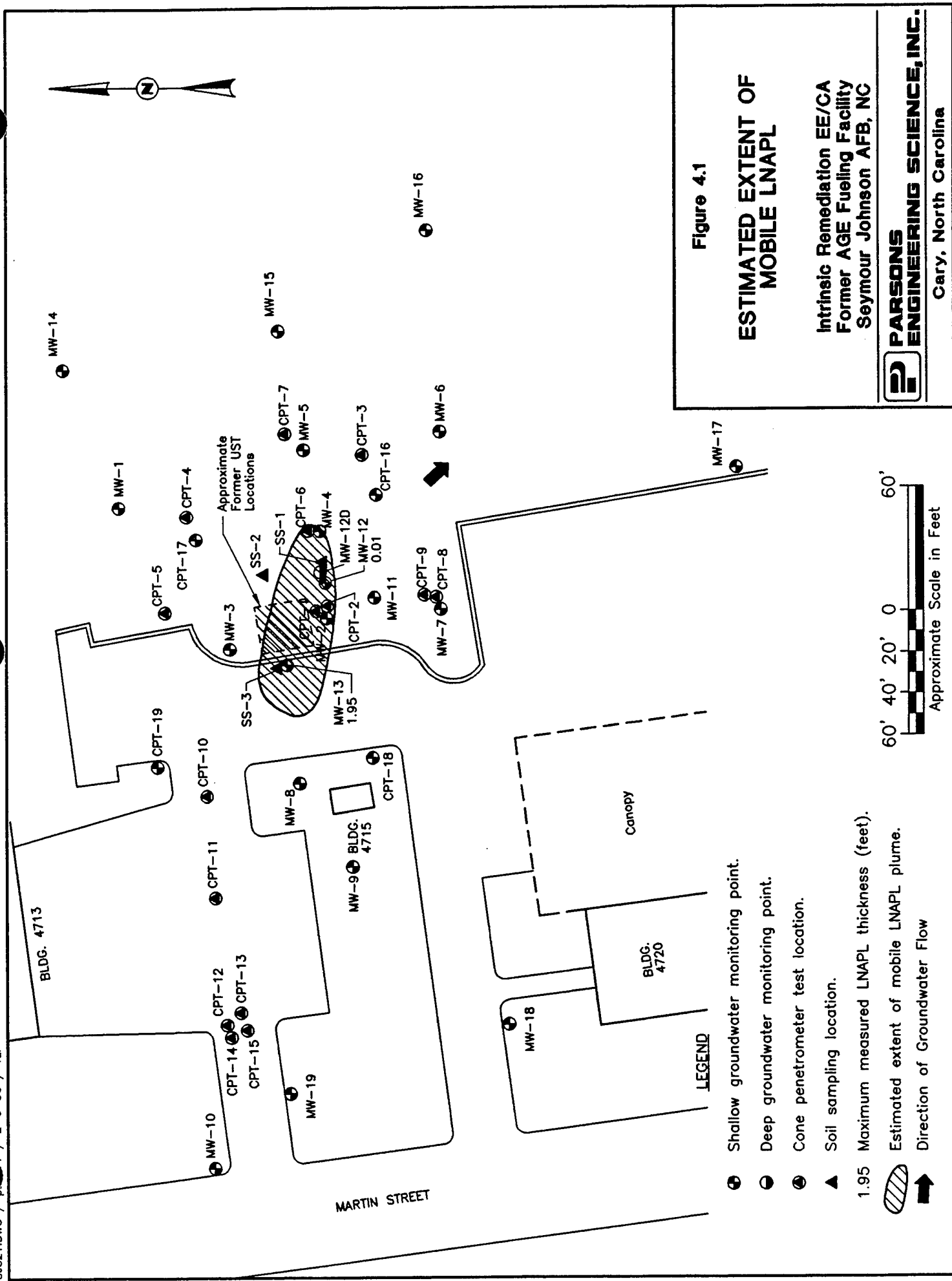


TABLE 4.1
FUEL HYDROCARBON COMPOUNDS DETECTED IN SOILS
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY
SEYMOUR JOHNSON AFB, NORTH CAROLINA

Sample Location ^{a/}	Sample Depth (ft bls) ^{b/}	Benzene (µg/kg)	Toluene (µg/kg)	Ethyl-benzene (µg/kg)	Total Xylenes (µg/kg)	Total BTEX ^{c/} (µg/kg)	Total TMBs ^{c/} (µg/kg)	Total Volatile Hydrocarbons ^{d/} (mg/kg)	Total Extractable Hydrocarbons ^{d/} (mg/kg)	LIF ^{e/} Results	
										Relative Intensity	Depth (ft bls)
Soil Test Locations											
MW-1	12 - 14	5 <	1 J	5 <	0.8 J	1.8	5 <	0.13 <	13 <	NA ^{f/}	NA
MW-2	9.5 - 10.5	25,000 <	3,800 J	4,300 J	12,000 J	20,100	158,000	660	2,300	NA	NA
MW-2	10.5 - 12	13,000 J	130,000	130,000	680,000	953,000	940,000	3,800 E	8,800	NA	NA
MW-4	12 - 13.5	4.6 <	1.1 J	1.4 J	11	13.5	13.5	0.110 <	19	NA	NA
MW-4	13.5 - 15	740	23,000	4,100 J	200,000	227,840	227,100	3,200 J	5,300	NA	NA
MW-5	13 - 14.5	5.2 <	0.7 J	5.2 <	2.3 J	3	8.2	0.130 <	13 <	NA	NA
MW-6	15 - 16	5.4 <	5.4 <	5.4 <	5.4 <	5.4 <	0.5	0.130 <	13 <	NA	NA
MW-8	11 - 12	5 <	5 <	5 <	0.7 J	0.7	5 <	0.130 <	13 <	NA	NA
MW-9	15 - 16	0.8 J	4.9 <	4.9 <	0.7 J	1.5	4.9 <	0.120 <	12 <	NA	NA
MW-10	10 - 11	5.1 <	0.7 <	5.1 <	1.6 J	1.6	5.8	0.130 <	13 <	NA	NA
MW-10	11 - 12	5.1 <	5.1 <	5.1 <	5.1 <	5.1 <	5.1 <	NS	NS	NA	NA
MW-11	11.5 - 13.5	6.2	4.2	2.8 J	33	46	35.8	0.130 <	13 <	NA	NA
SS-1	11.5 - 13.5	2,100 J	16,000	21,000	130,000	169,100	167,000	1,000 J	2,600	NA	NA
SS-1 dupl.	11.5 - 13.5	3,400 J	27,000	33,000	21,000	84,400	81,000	6,600 J	3,200	NA	NA
SS-1	16 - 18	0.9 J	5.1	4.3 <	1.1 <	6.0	4.3 <	0.110 <	11 <	NA	NA
SS-2	11.5 - 13.5	16	29	9.2	35 <	89	3.7	1.9	11 <	NA	NA
SS-3	9 - 11	630	8,100	9,600	43,000	61,330	17,700	5,200 J	4,100	NA	NA
SS-3 dupl.	9 - 11	9,200 J	8,500 J	12,000	45,000 <	74,700	20,500	2,300 E	4,800	NA	NA
CPT-2		NS ^{g/}	NS	NS	NS	NS	NS	NS	NS	16,000	11 - 13
CPT-3		NS	NS	NS	NS	NS	NS	NS	NS	425	10 - 11
CPT-4		NS	NS	NS	NS	NS	NS	NS	NS	1,000	12 - 13
CPT-5		NS	NS	NS	NS	NS	NS	NS	NS	1,200	10.5 - 11.5
CPT-6		NS	NS	NS	NS	NS	NS	NS	NS	15,000	13 - 14
CPT-7		NS	NS	NS	NS	NS	NS	NS	NS	425	11.5 - 12.5
CPT-8		NS	NS	NS	NS	NS	NS	NS	NS	1,200	15.5 - 16.5
CPT-10		NS	NS	NS	NS	NS	NS	NS	NS	2,000	9 - 10
CPT-11		NS	NS	NS	NS	NS	NS	NS	NS	1,500	8.5 - 10
CPT-12		NS	NS	NS	NS	NS	NS	NS	NS	1,800	7.5 - 8.5

^{a/} See Figure 4.2 for sample location
^{b/} ft bls = feet below land surface
^{c/} Quantified by Method SW8020
^{d/} Quantified by Method SW8015 modified with 5030/3550 extraction.
^{e/} LIF = Laser Induced Fluorescence readings (relative intensity).
A background LIF reading of 200 (relative intensity) was assumed.
^{f/} NA = not applicable.
^{g/} NS = not sampled.

Qualifiers:

< Compound concentration less than the reportable detection limit.
J Indicates an estimated value when the compound is detected, but is below the Practical Quantification Limit.
E Estimated value.

TABLE 4.2
FUEL HYDROCARBONS DETECTED IN GROUNDWATER
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY
SEYMOUR JOHNSON AFB, NORTH CAROLINA

Sample Location ^{a/}	Benzene ^{b/} (µg/L) ^{d/}	Toluene ^{b/} (µg/L)	Ethylbenzene ^{b/} (µg/L)	Total Xylenes ^{b/} (µg/L)	Total BTEX ^{b/} (µg/L)	Total Trimethyl- benzenes ^{b/} (µg/L)	Total Volatile Hydrocarbons (mg/L)	Total Extractable Hydrocarbons (mg/L)
Monitoring Points								
MW-3	280 B	18	140	170 B	608	75.5	3.2	2.6 J
MW-4	2,100	3,100	980	6,400	12,580	1200	17	8.2
MW-4 duplicate	2,300	3,300	1,100	7,100	13,800	1470	17	7.3
MW-5	240	4.6	4	95	344	59.2	1	1.4
MW-6	25	1	0.4 <	0.4 <	26	0.4 <	0.1 <	0.5 <
MW-7	180	11	120	100	411	46.3	0.1 <	0.6
MW-8	410	120	260	540	1,330	303	2.4	2.5 J
MW-10	0.4 <	5.3	2.6	4.4	12.3	9.7	0.1 <	0.5 <
MW-11	2,300 J	2,000 J	620	3,700 J	8,620	930 J	18	5.2
MW-12D	110	40	12	62	224	20.7	0.2	0.5
MW-13 (LNAPL)	1,000,000	3,500,000	2,300,000	7,300,000	14,100,000	10,000,000	NA ^{e/}	NA
MW-14	0.4 <	0.4 <	0.4 <	0.4 <	ND ^{f/}	0.4 <	0.1 <	0.5 <
MW-15	0.4 <	0.4 <	0.4 <	0.4 <	ND	0.4 <	0.1 <	0.5 <
MW-16	0.4 <	0.4 <	0.4 <	0.4 <	ND	0.4 <	0.1 <	0.5 <
MW-17	37	0.4 <	0.4 <	0.4 <	37	0.4 <	0.1	0.5 <
MW-18	0.4 <	0.4 <	0.4 <	1	1	0.4 <	0.1 <	0.5 <
MW-18 duplicate	0.4 <	1.1	0.4 <	0.4 <	1.1	0.4 <	0.1 <	0.5 <
MW-19	0.4 <	0.4 <	0.4 <	0.4 <	ND	0.4 <	0.1 <	0.5 <
CPT-16	2,100	2,100	560	4,100	8,860	960	14	14
CPT-17	61 <	18	88	260	366	68	1.8	1.3 J
CPT-18	820	200	170	500	1,690	366	2.8	1.8
CPT-19	0.4 <	0.4 <	0.4 <	0.4 <	0.4	0.4 <	0.1 <	0.5 <

^{a/} See Figure 4.3 for sample location.

^{b/} Quantified by Method SW8020.

^{c/} Quantified by Method SW8015 modified with 5030/3550 extraction.

^{d/} µg/L = micrograms per liter

^{e/} Not applicable.

^{f/} None detected.

Qualifiers:

<

Compound concentration less than the reportable detection limit

J

Indicates an estimated value when the compound is detected,

but is below the Practical Quantification Limit

B

Compound detected in laboratory method blank.

Concentrations of BTEX in the sample indicated that the petroleum product making up the LNAPL plume in this area is very weathered. Table 4.3 compares BTEX concentrations in fresh JP-4 to those observed in LNAPL from MW-13. Because gasoline and diesel fuel were also stored at the site, it is expected that the LNAPL is a mixture of gasoline and diesel fuel as well as JP-4.

The relationship between measured LNAPL thickness and the amount of mobile LNAPL in the subsurface at a site is extremely difficult to quantify. It is well documented that LNAPL thickness measurements taken in groundwater monitoring wells are not indicative of actual mobile LNAPL thicknesses in the formation (de Pastrovich *et al.*, 1979; Blake and Hall, 1984; Hall *et al.*, 1984; Hampton and Miller, 1988; Hughes *et al.*, 1988; Abdul *et al.*, 1989; Testa and Paczkowski, 1989; Kemblowski and Chiang, 1990; Lehnard and Parker, 1990; Mercer and Cohen, 1990; Ballesterio *et al.*, 1994). It has been noted by these authors that the thickness of LNAPL measured in a monitoring well is greater than the actual mobile LNAPL thickness present in the aquifer. According to Mercer and Cohen (1990), measured LNAPL thickness in wells is typically 2 to 10 times greater than the actual mobile LNAPL thickness in the formation.

4.3 SOIL CHEMISTRY

4.3.1 Residual Contamination

Residual NAPL is defined as the LNAPL that is trapped in subsurface material by cohesive and capillary forces. Therefore, residual LNAPL will not flow through the aquifer, nor will it flow from the aquifer matrix into a well under the influence of gravity. The following subsections describe the residual LNAPL contamination found at the site.

4.3.1.1 Soil BTEX Contamination

Residual hydrocarbon contamination resulting from vertical and lateral migration of free and dissolved hydrocarbons was found over an area slightly more extensive than the mobile LNAPL plume at the former AGE fueling area. Eighteen soil samples for laboratory analysis of BTEX, TEH, and TVH were collected from 12 locations, including samples from two depth intervals at four of the sampling locations and two duplicates. Table 4.1 contains analytical results for BTEX, total TMBs, TEH, and TVH in soil samples. Figure 4.2 shows the extent of contaminated soil as determined from laboratory analytical results.

Analyses of soil samples for total BTEX by USEPA Method SW8020 indicated soil BTEX concentrations ranging from 0.7 micrograms per kilogram ($\mu\text{g}/\text{kg}$) to 953,000 $\mu\text{g}/\text{kg}$ (Table 4.1). As observed at locations with soil samples collected at multiple depths, the highest BTEX concentrations were detected in soil samples collected near the capillary fringe. Lower BTEX concentrations were detected at shallower and deeper depths. The BTEX concentrations at SS-1 ranged from 169,100 $\mu\text{g}/\text{kg}$ in the capillary fringe zone sample (11.5 to 13.5 feet bls) to 6.0 $\mu\text{g}/\text{kg}$ at 16 to 18 feet bls. The deeper soil sample at SS-1 was collected from the top of the clay unit beneath the shallow aquifer. At MW-2 and MW-4 capillary fringe zone samples contained total BTEX concentrations of 953,000 $\mu\text{g}/\text{kg}$ and 227,100 $\mu\text{g}/\text{kg}$, respectively, while shallower

TABLE 4.3
MOBILE LNAPL RESULTS
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY
SEYMOUR JOHNSON AFB, NORTH CAROLINA

COMPOUND	CONCENTRATION IN FRESH JP-4 ^{a/} (mg/L) ^{b/}	CONCENTRATION IN PRODUCT FROM MW-13 ^{c/} (mg/L)
Benzene	3,750	1,000
Toluene	9,975	3,500
Ethylbenzene	2,775	2,300
Total Xylenes	17,400	7,300

^{a/} Data from Martel (1987).

^{b/} mg/L = Milligrams per liter

^{c/} Analyzed by Evergreen by EPA Method 8020

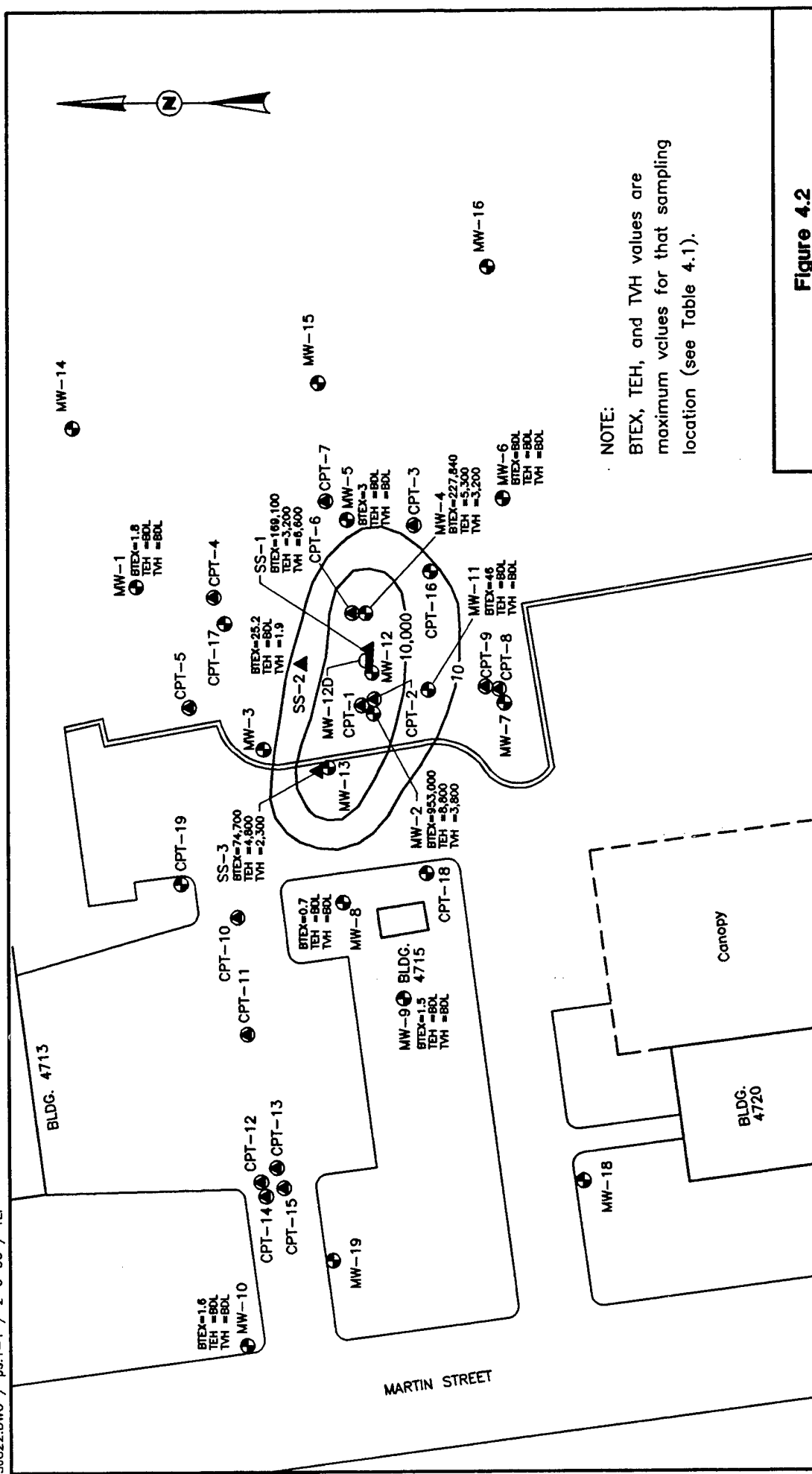


Figure 4.2

SOIL HYDROCARBON CONTAMINATION AS INDICATED BY LABORATORY ANALYSES

**Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC**



PARSONS

ENGINEERING SCIENCE, INC.

Cary, North Carolina

NOTE:

BTEX, TEH, and TVH values are maximum values for that sampling location (see Table 4.1).

LEGEND

- Shallow groundwater monitoring point.
 ○ Deep groundwater monitoring point.
 ⊙ Cone penetrometer test location.
 ▲ Soil sampling location.
- BTEX Total benzene, toluene, ethylbenzene and xylenes ($\mu\text{g}/\text{kg}$).
 BDL Below detection limit.
 —10— Total BTEX ($\mu\text{g}/\text{kg}$).
- TVH Total volatile hydrocarbon concentration (mg/kg).
 TEH Total extractable hydrocarbon concentration (mg/kg).
-
- Approximate Scale in Feet

samples had lower concentrations. Benzene was detected in soil samples from MW-2, MW-4, MW-9, MW-11, SS-1, SS-2, and SS-3 at concentrations ranging from 0.8 µg/kg to 13,000 µg/kg.

The laboratory results and LIF data indicate that contaminated soil extends along the direction of groundwater flow from the area between MW-13 and SS-3 to at least MW-4 and CPT-6 and laterally from SS-2 to MW-11. The area of soil contamination is approximately 100 feet long by 60 feet wide. The areal extent of residual soil contamination is similar to the areal extent of mobile LNAPL contamination, with additional lateral spreading of the residual contamination.

4.3.1.2 Soil TEH and TVH Contamination

Table 4.1 also shows TEH and TVH data for soil samples. Theoretically, because the BTEX compounds are a subset of the TVH compounds, the areas of BTEX and TVH contamination should be similar. The results of the TEH and TVH analyses by USEPA Method SW8015 (modified) correlate well with BTEX results. TVH concentrations at the former AGE fueling facility range from less than 0.110 milligrams per kilogram (mg/kg) to 6,600 mg/kg. TEH concentrations at the former AGE fueling facility range from less than 11 mg/kg to 4,800 mg/kg. Figure 4.2 shows TEH, TVH, and BTEX concentrations at the soil sampling locations.

4.3.2 Total Organic Carbon

TOC concentrations are used to estimate the amount of organic matter sorbed to soil particles or trapped in the interstices of a soil matrix. The TOC concentration in the saturated zone is an important parameter used to estimate the amount of contaminant that could potentially sorb to the aquifer matrix. Sorption results in retardation of the contaminant plume relative to the advective groundwater velocity. Parsons ES obtained soil core samples from MW-1, MW-5, MW-6, MW-10, and MW-11 for TOC analysis. The soil samples from MW-5 and MW-11 both contained TOC concentrations of 0.06 percent (approximately 600 mg/kg), but were contaminated by petroleum hydrocarbons. Samples from MW-6 and MW-10, which are relatively free from petroleum hydrocarbon contamination, contained TOC concentrations of 0.48 percent (approximately 4,800 mg/kg) and 0.12 percent (approximately 1,200 mg/kg), respectively. The sample from MW-1, which was also relatively free from petroleum hydrocarbon contamination, contained a TOC concentration of 0.06 percent (approximately 600 mg/kg).

4.4 GROUNDWATER CHEMISTRY

4.4.1 Dissolved Contamination

Groundwater samples were collected from 20 of the 23 monitoring points installed during this investigation. At the time of sampling, 3 of the monitoring points (MW-2, MW-9, and MW-12) had insufficient water for sampling. The groundwater analytical data

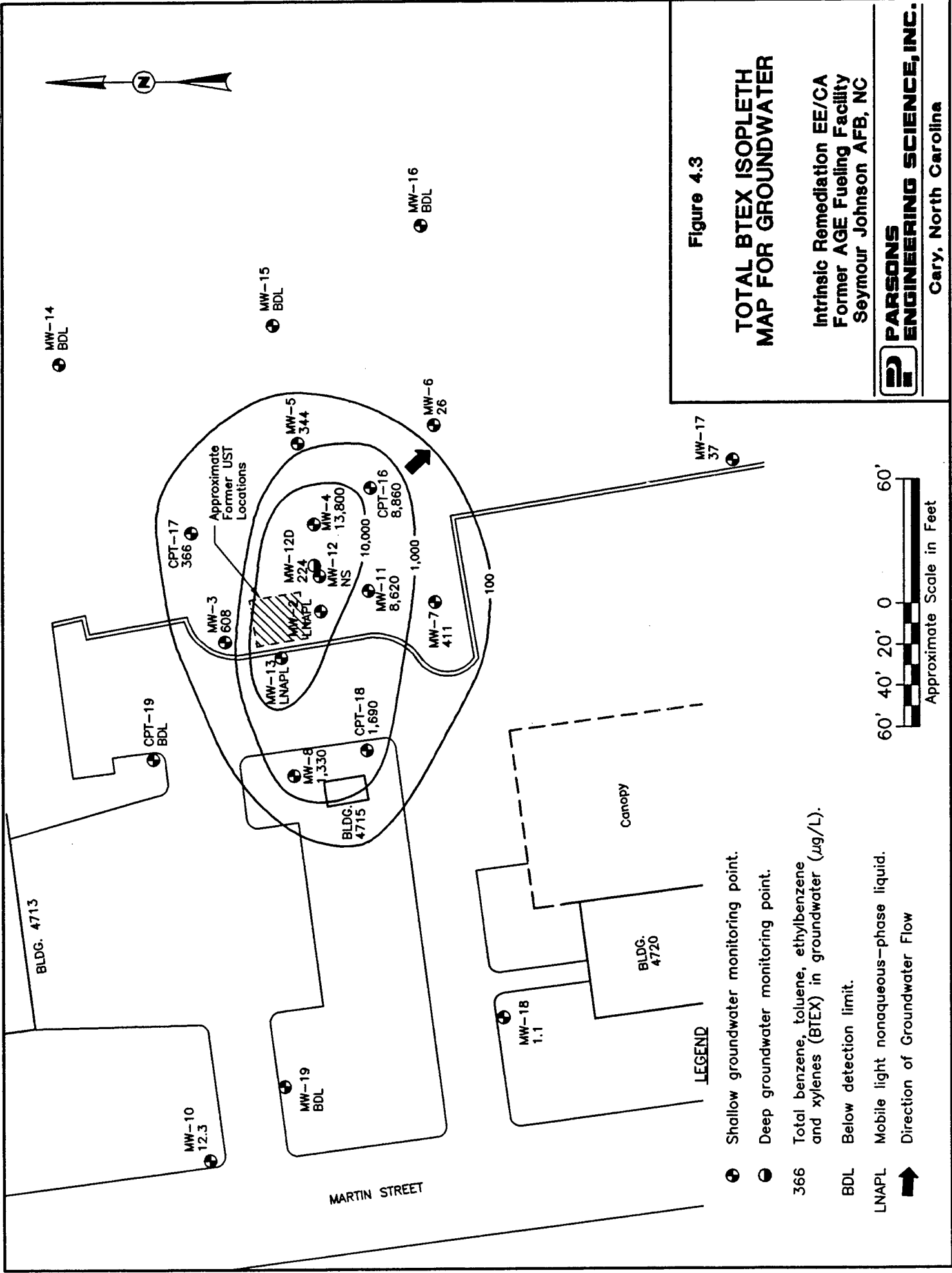
collected during this investigation are summarized in Table 4.2. Additional geochemical data related to the contaminant plume are discussed in Section 4.4.2.

4.4.1.1 BTEX in Groundwater

Figure 4.3 is an isopleth map that shows the distribution of total BTEX dissolved in groundwater. Isopleths are drawn based on the maximum BTEX concentration detected at each location. Because the shallow aquifer is only 5 to 8 feet thick, vertical concentration profiles were not generated for groundwater constituents at the site. However, one "deep" monitoring point (MW-12D) was installed to assess the vertical contaminant distribution within the shallow aquifer. While dissolved BTEX was not quantified at MW-12, the soil samples collected from the adjacent soil sampling location (SS-1) showed total BTEX concentrations ranging from 84,400 to 169,100 $\mu\text{g/kg}$ (Table 4.1). Additionally, mobile LNAPL has subsequently been detected in MW-12. The dissolved BTEX concentration in MW-12D, which was completed immediately above the clay confining unit beneath the shallow aquifer, was 224 micrograms per liter ($\mu\text{g/L}$). These results suggest that there is limited vertical migration of petroleum contamination within the shallow aquifer at the former AGE fueling facility site.

The primary direction of migration of dissolved BTEX contamination in groundwater is to the southeast (the primary direction of flow at the site). Dissolved BTEX contamination also appears to have migrated from the source area at the former AGE fueling facility site to the west, northeast, and east. As delineated by the 10- $\mu\text{g/L}$ total BTEX isopleth, the northwest- to southeast-trending portion of the contaminant plume is approximately 315 feet long. In the primary direction of flow (southeast), the plume extends approximately 260 feet downgradient from the source area (as measured from MW-13). The plume also extends approximately 110 feet to the west of the source area. To the east of the source area, the plume extends approximately 140 feet. Because the aquifer is thin throughout and mounds in the vicinity of the source area, diffusion and density-driven flow of mobile LNAPL likely have been important factors in the distribution of BTEX contamination from the UST release. In addition, differential recharge due to paved versus natural areas may have an effect on groundwater flow patterns and BTEX migration.

Thirteen of the site monitoring points that were sampled during this investigation contained groundwater with reportable dissolved benzene concentrations above the North Carolina groundwater standard of 1 $\mu\text{g/L}$. Where detected, dissolved benzene concentrations ranged from 25 $\mu\text{g/L}$ at MW-6 to 2,300 $\mu\text{g/L}$ at MW-11 and MW-4 (duplicate analysis). Toluene concentrations exceeded the North Carolina standard and federal Maximum Contaminant Level (MCL) (1,000 $\mu\text{g/L}$) in monitoring points MW-4, MW-11, MW-13, and CPT-16. Concentrations of ethylbenzene exceeded the North Carolina standard (29 $\mu\text{g/L}$) in monitoring points MW-4, MW-8, MW-11, MW-12D, MW-13, CPT-16, CPT-17, and CPT-18. Xylene concentrations above the North Carolina standard (530 $\mu\text{g/L}$) were detected in monitoring points MW-4, MW-8, MW-11, MW-13, and CPT-16.



4.4.1.2 Additional Compounds in Groundwater

In addition to the standard analytical methods for projects under the AFCEE intrinsic remediation demonstration program, several monitoring points were sampled for additional compounds required under the North Carolina Petroleum UST regulations. Samples from monitoring points MW-3, MW-4, MW-5, MW-8, MW-11, MW-12D, and CPT-18 were analyzed by USEPA Method 624 for quantification of methyl tert-butyl ether (MTBE), isopropyl ether (IPE), and ethylene dibromide (EDB). Table 4.4 summarizes the results of these analyses. The concentrations of MTBE detected in samples from these monitoring points ranged from 1 µg/L at MW-12D to 32 µg/L at MW-11, all of which were below the North Carolina groundwater standard of 200 µg/L. Concentrations of IPE ranged from 2 µg/L at MW-12D to 31 µg/L at MW-11 (there is no quantified standard in North Carolina for IPE). No EDB concentrations were detected in these monitoring points above the 1-µg/L detection limit.

A groundwater sample from MW-4 also was analyzed for total lead by Method 3030C and semivolatile organic compounds (SVOCs) by USEPA Method 625. Lead was not detected above the 55-µg/L detection limit. Several SVOCs were detected in MW-4. Naphthalene was detected at 180 µg/L, (exceeding the North Carolina standard of 21 µg/L). Phenanthrene was detected at 11 µg/L, below the standard of 210 µg/L. Other compounds detected for which no numerical standard has been set by North Carolina were 2-methylnaphthalene (57 µg/L), acenaphthylene (2 µg/L), acenaphthene (5 µg/L), anthracene (3 µg/L), fluoranthene (2 µg/L), pyrene (1 µg/L), bis(2-ethylhexyl) phthalate (1 µg/L), 2-methylphenol (11 µg/L), and 4-methylphenol (11 µg/L). These compounds are commonly found in gasoline, diesel, and JP-4.

4.4.2 Groundwater Geochemistry

Microorganisms obtain energy for cell production and maintenance by facilitating the transfer of electrons from electron donors to electron acceptors. This results in the oxidation of the electron donor and the reduction of the electron acceptor. Potential electron donors at the former AGE fueling facility are natural organic carbon constituents and fuel hydrocarbon compounds. Fuel hydrocarbons are completely degraded or detoxified if they are utilized as the primary electron donor for microbial metabolism (Bouwer, 1992). Electron acceptors are elements or compounds that occur in relatively oxidized states and include DO (O₂), nitrate (NO₃⁻), ferric iron (Fe⁺³), sulfate (SO₄⁻²), and carbon dioxide (CO₂). Microorganisms preferentially utilize electron acceptors while metabolizing fuel hydrocarbons (Bouwer, 1992). DO is utilized first by aerobic organisms as the primary electron acceptor. After the DO is consumed, anaerobic microorganisms use electron acceptors in the following order of preference: nitrate, ferric iron, sulfate, and finally carbon dioxide.

Depending on the type of electron acceptors present (e.g., nitrate, iron, sulfate, carbon dioxide), pH conditions, and redox potential, anaerobic biodegradation can occur by denitrification, ferric iron reduction, sulfate reduction, or methanogenesis. Other, less common anaerobic degradation mechanisms such as manganese reduction may dominate if the physical and chemical conditions in the subsurface favor the use of these electron acceptors. Anaerobic destruction of the BTEX compounds is associated with the

TABLE 4.4
ADDITIONAL COMPOUNDS DETECTED IN GROUNDWATER
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY
SEYMOUR JOHNSON AFB, NORTH CAROLINA

Sample Location	MTBE ($\mu\text{g/L}$)	IPE ($\mu\text{g/L}$)	EDB ($\mu\text{g/L}$)
MW-3	19	4	1 U
MW-4	14	3	1 U
MW-5	4	8	1 U
MW-8	2	13	1 U
MW-11	32	31	1 U
MW-12D	1	2	1 U
CPT-18	8	28	1 U

U = not detected at reporting limit.

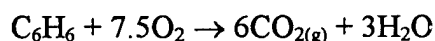
accumulation of fatty acids, production of methane, solubilization of iron, and reduction of nitrate and sulfate (Cozzarelli et al., 1990; Wilson et al., 1990). Environmental conditions and microbial competition will ultimately determine which processes will dominate. Vroblesky and Chapelle (1994) show that the dominant terminal electron accepting process can vary both temporally and spatially in a fuel-hydrocarbon-contaminated aquifer.

Geochemical data obtained at the former AGE fueling facility site indicate that intrinsic remediation of hydrocarbons in the shallow aquifer may be occurring by aerobic oxidation, ferric iron reduction, sulfate reduction, and methanogenesis. This is evidenced by significant changes in groundwater geochemistry in comparison to background conditions. Areas of the site that show the greatest variation in concentrations of geochemical parameters generally correspond well with areas of high BTEX concentration. Table 4.5 summarizes groundwater geochemical data gathered during the intrinsic remediation demonstration project at Seymour Johnson AFB. Geochemical parameters for the former AGE fueling facility site are discussed in the following sections.

4.4.2.1 Dissolved Oxygen

DO concentrations were measured in groundwater samples from the monitoring points at the site during the two 1995 sampling events. Table 4.5 includes a summary of measured DO concentrations. Figure 4.4 is an isopleth map showing the horizontal distribution of DO concentrations in groundwater at the former AGE fueling facility site. Comparison of Figure 4.3 with Figure 4.4 shows graphically that the horizontal distribution of groundwater with elevated total BTEX concentrations corresponds to the distribution of groundwater with reduced DO concentrations. The lowest measured DO concentration at the site was 0.18 milligrams per liter (mg/L), measured at MW-12D. These data provide a strong indication that aerobic biodegradation of the BTEX compounds is occurring at the site. Background DO concentrations measured at MW-10, CPT-19, MW-14, and MW-15 were 8.25 mg/L, 9.06 mg/L, 6.20 mg/L, and 6.90 mg/L, respectively, indicating that DO is likely an important electron acceptor at the former AGE fueling facility site.

The following equations describe the overall stoichiometry of aromatic hydrocarbon mineralization caused by aerobic microbial biodegradation. In the absence of microbial cell production, the oxidation (mineralization) of benzene to carbon dioxide and water is given by:



Therefore, 7.5 moles of oxygen are required to metabolize 1 mole of benzene. On a mass basis, the ratio of oxygen to benzene is given by:

Molecular weights:	Benzene	$6(12) + 6(1) = 78$ grams per mole (gm/mole)
	Oxygen	$2(16) = 32$ gm/mole
	Mass Ratio of Oxygen to Benzene	$= 7.5(32)/78 = 3.08:1$

Therefore, in the absence of microbial cell production, 3.08 milligrams (mg) of oxygen are required to completely metabolize 1 mg of benzene.

TABLE 4.5
GROUNDWATER GEOCHEMICAL DATA
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY
SEYMOUR JOHNSON AFB, NORTH CAROLINA

Sample Location ^{a/}	Water Temp. ^{b/} (°C)	pH ^{b/}	Dissolved Oxygen ^{b/} (mg/L)	Redox Potential ^{b/} (mV)	Nitrate as N (mg/L)	Total Alkalinity ^{c/} (mg/L)	Sulfate ^{d/} (mg/L)	Sulfide ^{d/} (mg/L)	Ferrous Iron ^{d/} (mg/L)	Conductivity ^{b/} (μmhos/cm)	Methane ^{e/} (mg/L)	Carbon Dioxide ^{d/} (ppm)	Ammonia ^{d/} (ppm)
CPT-16	18.7	6.81	3.25	22.8	NS ^{f/}	95	4.2	0.013	16.25	220	0.037	> 100	5.00
CPT-17	15.2	6.67	0.51	70.1	< .056	20	0.7	0.316	4.41	70	0.12	> 100	0.10
CPT-18	16.7	5.88	0.73	81.0	< .056	80	4.3	0.053	18.10	170	0.15	> 100	> 10
CPT-19	16.6	5.57	9.06	153.9	0.058	10	12.5	0.034	2.26	50	< .004	35	0.10
MW-2	NS ^{f/}	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MW-3	18.5	5.64	1.29	62.8	< .056	130	7.6	0.133	24.20	300	1.92	> 100	> 10
MW-4	15.9	5.70	0.26	71.9	< .056	80	16.7	0.018	31.63	250	< .004	> 100	> 10
MW-5	18.1	5.82	1.64	216.2	< .056	10	9.0	0.012	1.48	100	0.15	> 100	ND
MW-6	15.1	5.07	0.94	-93.4	NS	10	3.9	0.008	2.24	60	0.035	100	0.00
MW-7	17.2	6.10	1.23	95.3	NS	40	10.2	ND ^{g/}	9.45	130	0.001	> 100	NS
MW-8	17.6	5.98	0.97	102.2	< .056	15	6.1	0.014	5.55	90	2.70	> 100	0.30
MW-9	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MW-10	21.2	5.94	8.25	136.4	NS	15	9.8	ND	1.43	70	< .004	26	0.00
MW-11	18.2	6.92	0.24	34.4	NS	130	10.6	0.056	23.20	270	0.20	> 100	> 10
MW-12	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MW-12D	17.1	8.80	0.18	153	NS	20	1.0	0.0	5.0	70	0.13	> 100	0.6
MW-13	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS	NS
MW-14	20.0	5.12	6.20	312	< .056	NA ^{h/}	11.8	NA	0.05	NA	< .004	NA	NA
MW-15	19.0	5.10	6.90	232	0.100	NA	44.1	NA	0.37	NA	< .004	NA	NA
MW-16	22.0	5.00	3.90	203	< .056	NA	28.9	NA	1.27	NA	0.142	NA	NA
MW-17	22.5	4.96	1.80	204	0.360	NA	33.6	NA	0.09	NA	0.006	NA	NA
MW-18	23.0	5.00	4.40	278	1.700	NA	47.0	NA	0.04	NA	< .004	NA	NA
MW-19	23.0	5.07	1.30	140	0.076	NA	19.3	NA	0.80	NA	0.046	NA	NA

^{a/} See Figure 4.3 for sample locations.

^{b/} Quantified by portable field instruments (see Section 2.0).

^{c/} Quantified by Method A403.

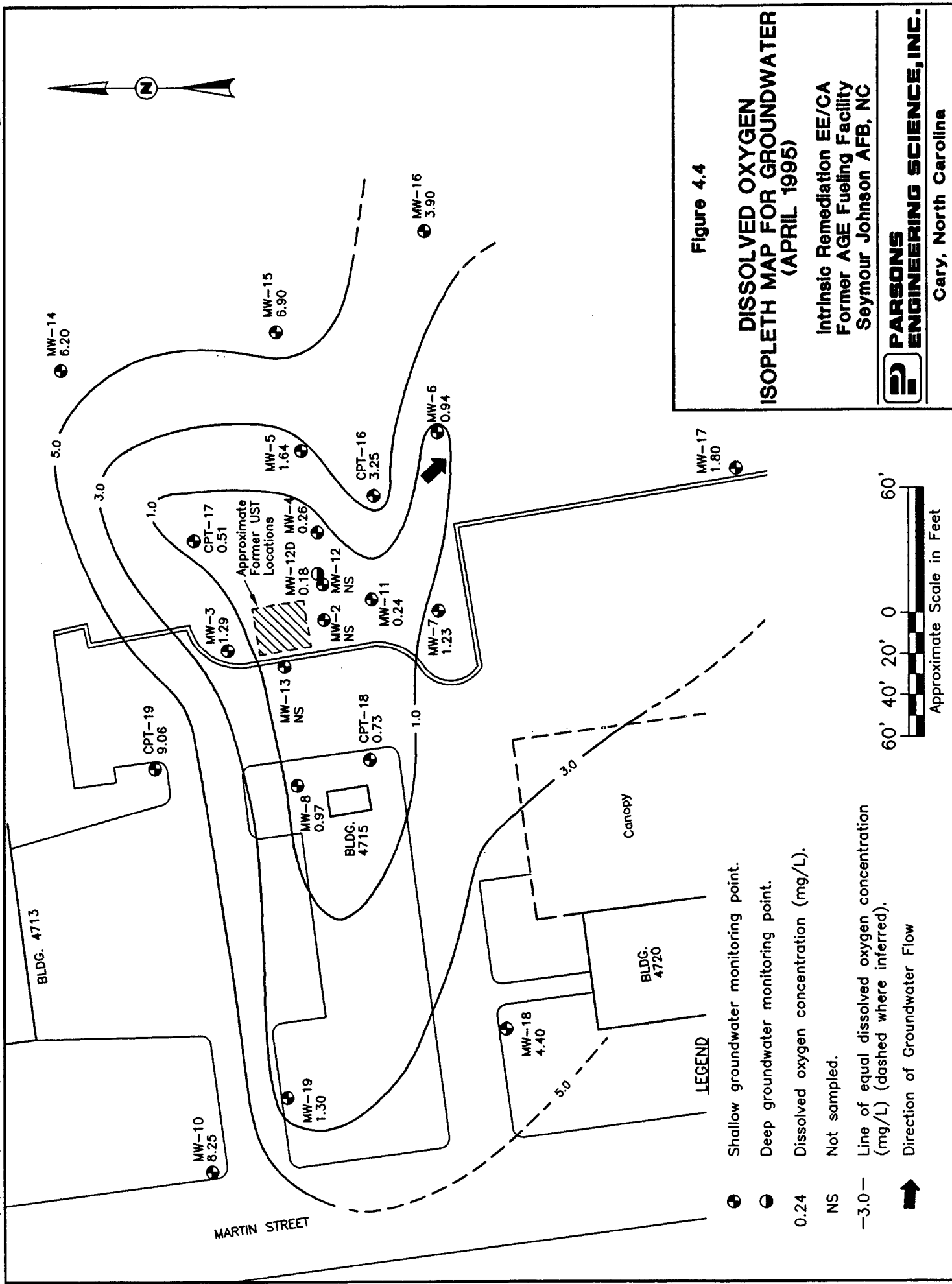
^{d/} Quantified by Hach field tests.

^{e/} Quantified by USEPA Method RSKSOP-175.

^{f/} NS = Not sampled.

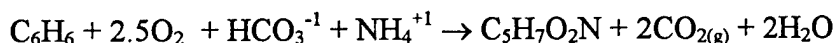
^{g/} ND = Not detected.

^{h/} NA = Not analyzed.



Similar calculations can be applied for toluene (3.13 mg oxygen to 1 mg toluene), ethylbenzene (3.17 mg oxygen to 1 mg ethylbenzene), and xylenes (3.17 mg oxygen to 1 mg xylene). The average mass ratio of oxygen to total BTEX is thus 3.14:1. This means that approximately 0.32 mg of BTEX is mineralized for every 1.0 mg of DO consumed. As a conservative estimate, a background DO concentration of 6 mg/L was assumed. Based on this assumption, the shallow groundwater at this site has the capacity to assimilate 1.92 mg/L (1,920 µg/L) of total BTEX. This may be a conservative estimate of the expressed assimilative capacity of DO because microbial cell mass production was not taken into account by the stoichiometry shown above.

When cell mass production is accounted for, the mineralization of benzene to carbon dioxide and water is given by:



Note that only 2.5 moles of DO are required to mineralize 1 mole of benzene when cell mass production is taken into account. On a mass basis, the ratio of DO to benzene is given by:

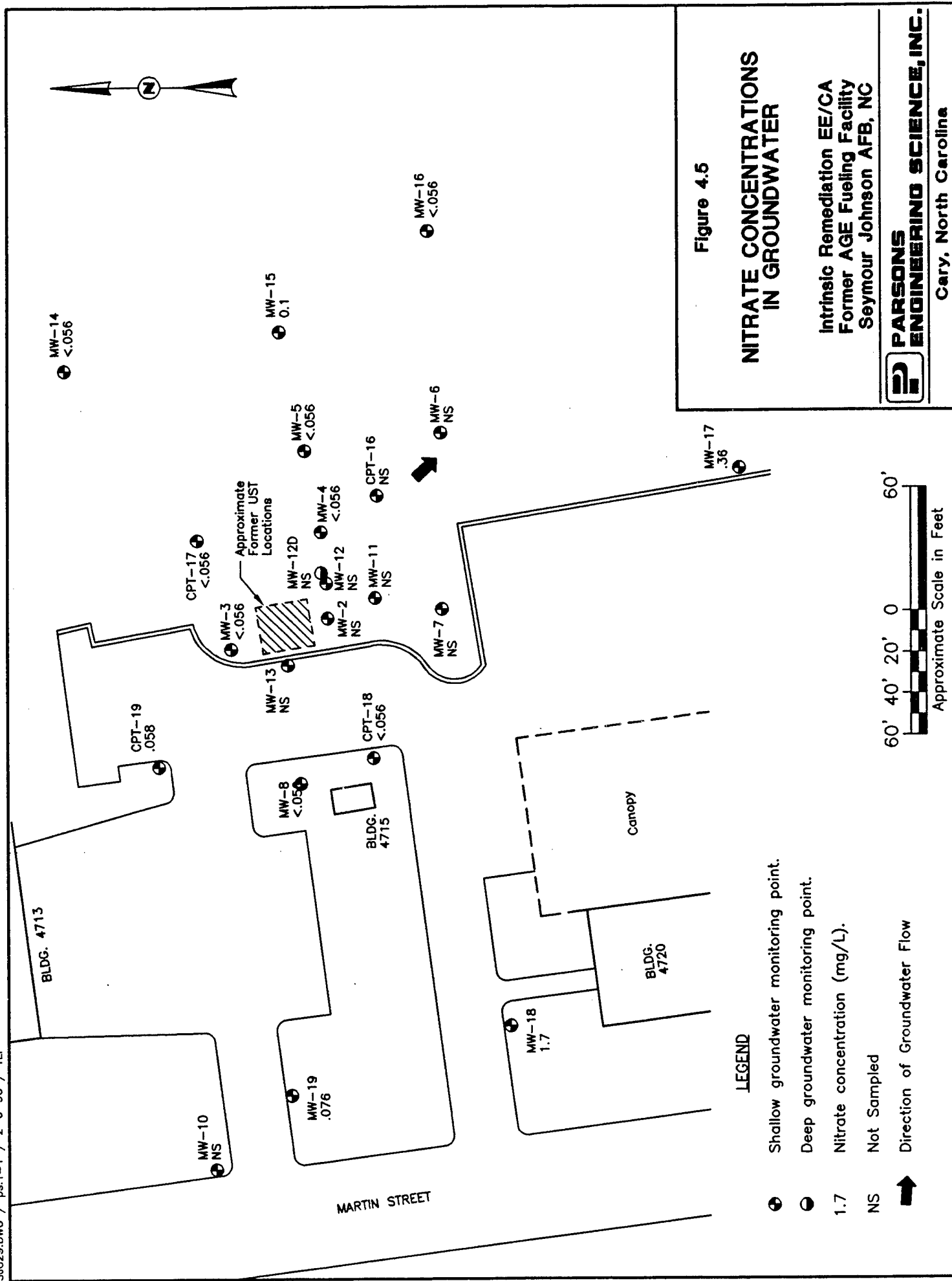
Molecular weights:	Benzene	6(12) + 6(1) = 78 gm/mole
	Oxygen	2(16) = 32 gm/mole

Mass ratio of oxygen to benzene = 2.5(32)/78 = 1.03:1

Based on these stoichiometric relationships, 1.03 mg of oxygen are required to convert 1 mg of benzene into biomass, CO₂, and H₂O. Similar calculations can be made for toluene, ethylbenzene, and xylenes. Based on these calculations, approximately 0.97 mg of BTEX is converted into biomass and mineralized to carbon dioxide and water for every 1.0 mg of DO consumed. With an assumed conservative background DO concentration of 6 mg/L, the shallow groundwater at the former AGE fueling facility site has the capacity to assimilate 5.82 mg/L (5,820 µg/L) of total BTEX.

4.4.2.2 Nitrate/Nitrite

Concentrations of nitrate + nitrite [as nitrogen (N)] were measured in selected groundwater monitoring points in April and July 1995. Nitrate concentrations are summarized in Table 4.5. No nitrite concentrations were measured above the detection limit of 0.076 mg/L in the groundwater samples. As a result, only nitrate concentrations were considered to be an indicator of ongoing denitrification at the site. Nitrate concentrations were relatively low throughout the site. The highest observed nitrate concentration was 1.7 mg/L at MW-18. The BTEX concentration detected in MW-18 was only 1 µg/L. Elsewhere, background nitrate concentrations range from below the detection level of 0.056 mg/L to 0.1 mg/L. Based upon these data, background nitrate concentrations at the site may range from less than 0.056 mg/L to 1.7 mg/L. Figure 4.5 shows the distribution of nitrate (as N) concentrations. Comparison with Figure 4.3 shows graphically that areas with elevated total BTEX concentrations generally have lower or nondetectable nitrate concentrations. All locations with BTEX concentrations in excess of 100 µg/L had nitrate concentrations below the detection level.



The absence of detected nitrate concentrations in the center of the BTEX plume suggest that anaerobic biodegradation of BTEX is occurring through the microbially mediated process of denitrification. However, nitrate reduction is probably a minor removal mechanism at the site. As a conservative assumption, a background nitrate (as N) concentration of 0.2 to 0.25 mg/L was utilized in this analysis to estimate assimilative capacity by denitrification. This is equivalent to a nitrate concentration of approximately 1 mg/L.

In the absence of microbial cell production, the biodegradation of benzene to carbon dioxide and water by the denitrification process is given by:



Based on this relationship, 6 moles of nitrate are required to mineralize 1 mole of benzene. On a mass basis, the ratio of nitrate to benzene is given by:

Molecular weights:	Benzene	$6(12) + 6(1) = 78 \text{ gm/mole}$
	Nitrate	$14 + 3(16) = 62 \text{ gm/mole}$
	Mass ratio of nitrate to benzene	$= 6(62)/78 = 4.77:1$

In the absence of microbial cell production, 4.77 mg of nitrate are required to completely mineralize 1 mg of benzene. Similar calculations can be completed for toluene (4.85 mg of nitrate to 1 mg toluene), ethylbenzene (4.92 mg nitrate to 1 mg ethylbenzene), and the xylenes (4.92 mg nitrate to 1 mg xylene). The average mass ratio of nitrate consumed to total BTEX degraded is 4.86:1. This means that approximately 0.20 mg of BTEX is mineralized for every 1.0 mg of nitrate consumed. With an assumed background nitrate concentration of 1 mg/L, the shallow groundwater at this site has the capacity to assimilate 0.2 mg/L (200 µg/L) of total BTEX during denitrification. This may be a conservative estimate of the expressed assimilative capacity of nitrate because microbial cell mass production has not been taken into account by the stoichiometry shown above (see Section 4.4.2.1).

4.4.2.3 Ferrous Iron

Ferrous iron concentrations were measured in samples from groundwater monitoring points and are included in the data summary in Table 4.5. Figure 4.6 is an isopleth map showing the distribution of ferrous iron in groundwater. Comparison of Figures 4.6 and 4.3 shows graphically that the areal distribution of higher ferrous iron concentrations correspond well to areas of higher BTEX concentrations. This suggests that ferric iron is being reduced to ferrous iron during biodegradation of BTEX compounds. The highest measured ferrous iron concentrations were generally detected in monitoring points that exhibited the highest BTEX concentrations (in the central portion of the contaminant plume). In addition, a lower ferrous iron concentration was detected at depth within the plume area in MW-12D, where the BTEX concentration was lower than those observed in adjacent shallow wells.

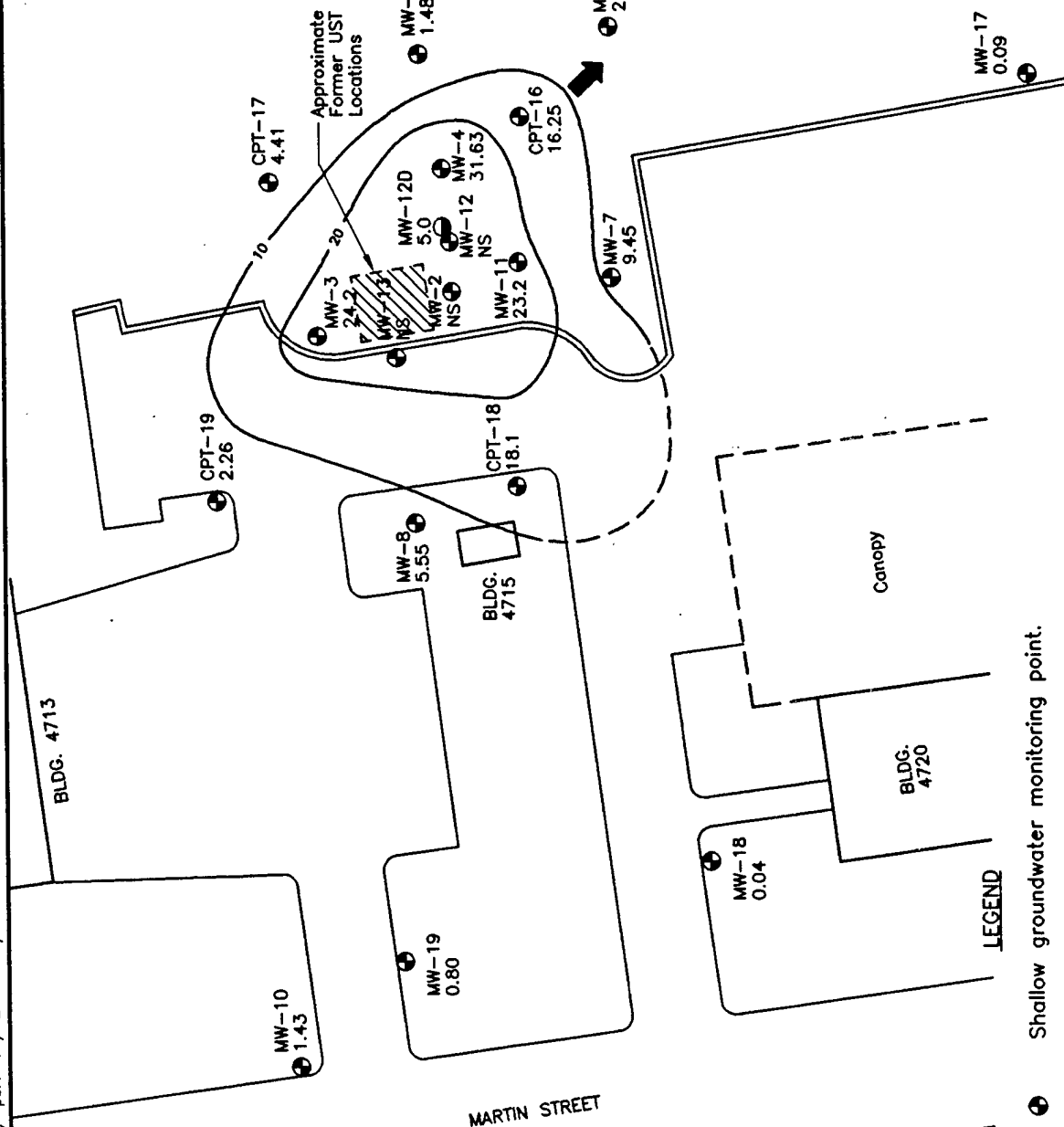


Figure 4.6

FERROUS IRON ISOPLETH MAP FOR GROUNDWATER

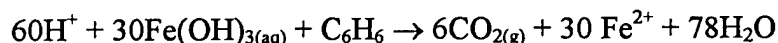
Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC



**PARSONS
ENGINEERING SCIENCE, INC.**

Cary, North Carolina

The following equations describe the overall stoichiometry of benzene degradation by ferric iron reduction. In the absence of microbial cell production, the mineralization of benzene by iron reduction is given by:



Therefore, 30 moles of ferric iron are required to metabolize 1 mole of benzene. On a mass basis, the ratio of ferric iron to benzene is given by:

Molecular weights: Benzene $6(12) + 6(1) = 78$ gm/mole

Ferric Iron Hydroxide $55.85 + 3(16) + 3(1) = 106.85$ gm/mole

Mass ratio of ferric iron to benzene $= 30(106.85)/78 = 41.0:1$

Therefore, in the absence of microbial cell production, 41.0 mg of ferric iron are required to completely metabolize 1 mg of benzene. Alternatively, the mass ratio of ferrous iron produced during respiration to benzene degraded can be calculated and is given by:

Molecular weights: Benzene $6(12) + 6(1) = 78$ gm/mole

Ferrous Iron 55.85 gm/mole

Mass ratio of ferrous iron to benzene $= 30(55.85)/78 = 21.5:1$

Therefore, 21.5 mg of ferrous iron (Fe^{2+}) are produced during mineralization of 1 mg of benzene. Similar calculations can be completed for toluene (21.86 mg of Fe^{2+} produced during mineralization of 1 mg of toluene), ethylbenzene (22 mg of Fe^{2+} produced during mineralization of 1 mg of ethylbenzene), and the xylenes (22 mg of Fe^{2+} produced during mineralization of 1 mg of xylene). The average mass ratio of Fe^{2+} produced during total BTEX mineralization is thus 21.8:1. This means that approximately 1 mg of BTEX is mineralized for every 21.8 mg of Fe^{2+} produced.

The highest measured Fe^{2+} concentration was 31.63 mg/L at MW-4. This suggests that the shallow groundwater at this site has the capacity to assimilate at least 1.45 mg/L (1,450 $\mu\text{g/L}$) of total BTEX during iron reduction. This may be a conservative estimate of the expressed assimilative capacity of iron in groundwater because microbial cell mass production has not been taken into account by the stoichiometry shown above (see Section 4.4.2.1). In addition, this calculation is based on measured ferrous iron concentrations and not on the amount of ferric hydroxide available in the aquifer. Therefore, iron assimilative capacity could be much greater.

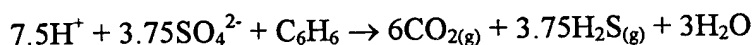
Recent evidence suggests that the reduction of ferric iron to ferrous iron cannot proceed at all without microbial mediation (Lovley and Phillips, 1988; Lovley *et al.*, 1991; Chapelle, 1993). None of the common organic compounds found in low-temperature, neutral, reducing groundwater could reduce ferric orthohydroxides to ferrous iron under sterile laboratory conditions (Lovley *et al.*, 1991). This means that the reduction of ferric iron requires microbial mediation by microorganisms with the appropriate enzymatic capabilities. Because the reduction of ferric iron cannot proceed without microbial intervention, the elevated concentrations of ferrous iron that were measured in the contaminated groundwater at the site are very strong indicators of microbial activity.

4.4.2.4 Sulfate

Sulfate concentrations were measured in samples from groundwater monitoring points at the site. Table 4.5 includes a summary of sulfate concentrations measured at the site. Figure 4.7 is an isopleth map showing the horizontal distribution of sulfate ion in groundwater. Comparison of Figures 4.7 and 4.3 shows graphically that, in general, the areas with the lowest sulfate ion concentrations in groundwater correspond to areas with the highest BTEX concentrations. This suggests that sulfate is being reduced during biodegradation of BTEX compounds. The highest measured sulfate ion concentration was 47.0 mg/L at MW-18. Significant sulfate concentrations also were measured at MW-15 (44.1 mg/L), MW-16 (28.9 mg/L), MW-17 (33.6 mg/L), and MW-19 (19.3 mg/L), which are located outside or at the fringes of the BTEX plume. Background sulfate concentrations may range from 30 mg/L to 50 mg/L. As a conservative estimate, the background sulfate concentration for the former AGE fueling facility site was assumed to be 40 mg/L. Sulfate depletion was noted at monitoring points CPT-17 (0.7 mg/L), MW-12D (1.0 mg/L), MW-6 (3.9 mg/L), CPT-16 (4.2 mg/L), and CPT-18 (4.3 mg/L). These monitoring points generally are located near the center of the BTEX plume. In general, sulfate concentrations were reduced to below 10 mg/L near the center of the BTEX plume.

Concentrations of sulfide (see Table 4.5) also were measured in selected monitoring points at the site. However, the distribution of sulfide concentrations measured in groundwater samples at the site do not correlate well with the distribution of sulfate concentrations. The lack of a regular trend in sulfide concentrations may be due to the strong affinity of certain aquifer matrix minerals for the sulfide ion. High levels of iron and manganese compounds are generally contained within aquifer matrices. The sulfide ion will react with iron and manganese to form insoluble metallic sulfides.

The following equations describe the overall stoichiometry of BTEX oxidation by sulfate reduction caused by anaerobic microbial biodegradation. In the absence of microbial cell mass production, the biodegradation of benzene is given by:

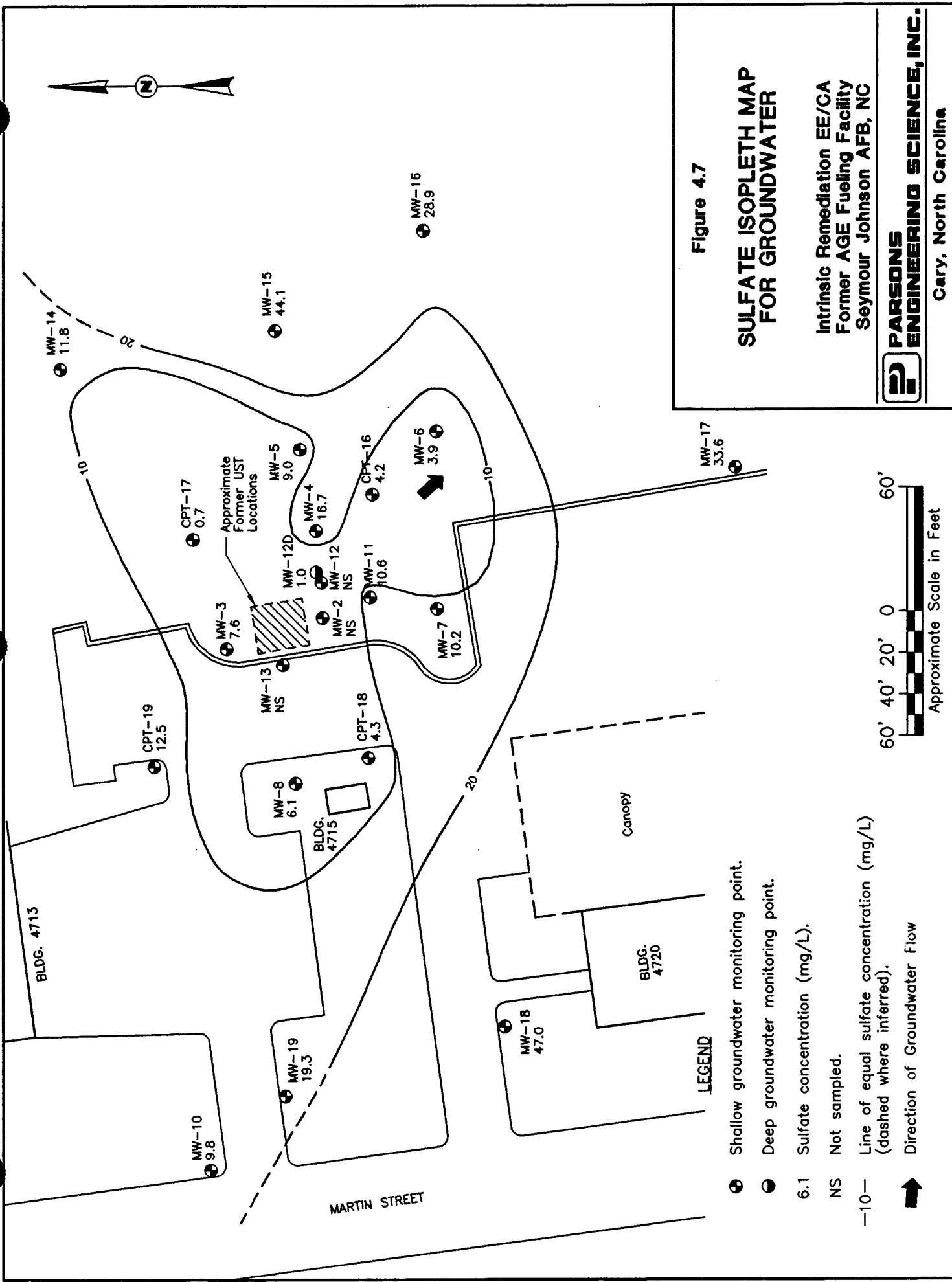


Therefore, 3.75 moles of sulfate are required to mineralize 1 mole of benzene. On a mass basis, the ratio of sulfate to benzene is given by:

Molecular weights:	Benzene	$6(12) + 6(1) = 78$ gm/mole
	Sulfate	$32.06 + 4(16) = 96.06$ gm/mole

$$\text{Mass ratio of sulfate to benzene} = 3.75(96.06)/78 = 4.6:1$$

Therefore, in the absence of microbial cell production, 4.6 mg of sulfate are required to completely mineralize 1 mg of benzene. Similar calculations can be completed for toluene (4.7 mg sulfate to 1 mg toluene), ethylbenzene (4.75 mg sulfate to 1 mg ethylbenzene), and the xylenes (4.75 mg sulfate to 1 mg xylene). The average mass ratio of sulfate to total BTEX is thus 4.7:1. This means that approximately 0.21 mg of BTEX is mineralized for every 1.0 mg of sulfate consumed. Assuming a background sulfate concentration of 40 mg/L, the shallow groundwater at the former AGE fueling facility site has the capacity to assimilate 8.4 mg/L (8,400 µg/L) of total BTEX during sulfate reduction. Again, this

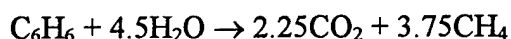


may be a conservative estimate of the expressed assimilative capacity of sulfate because microbial cell mass production has not been taken into account by the stoichiometry shown above (see Section 4.4.2.1).

4.4.2.5 Methane

Methane concentrations were measured in samples from groundwater monitoring points at the site. Table 4.5 includes a summary of the measured methane concentrations. Figure 4.8 is an isopleth map showing the distribution of methane in groundwater at the former AGE fueling facility site. Comparison of Figure 4.8 to Figure 4.3 shows graphically that areas with elevated BTEX concentrations generally correlate with areas with elevated methane concentrations. High methane concentrations were measured in MW-8 and MW-3 (2.7 mg/L and 1.92 mg/L, respectively) where BTEX concentrations also were high (1,330 µg/L and 608 µg/L, respectively). Concentrations of methane were below the method detection limit (0.004 mg/L) outside of the BTEX plume in MW-10, MW-14, MW-15, and MW-18. These data indicate that methanogenesis is an anaerobic biodegradation pathway for BTEX at the former AGE fueling facility site.

The following equations describe the overall stoichiometry of benzene oxidation by methanogenesis where carbon dioxide is utilized as the terminal electron acceptor. In the absence of microbial cell production, the mineralization of benzene is given by:



The mass ratio of methane produced during respiration to benzene degraded can be calculated and is given by:

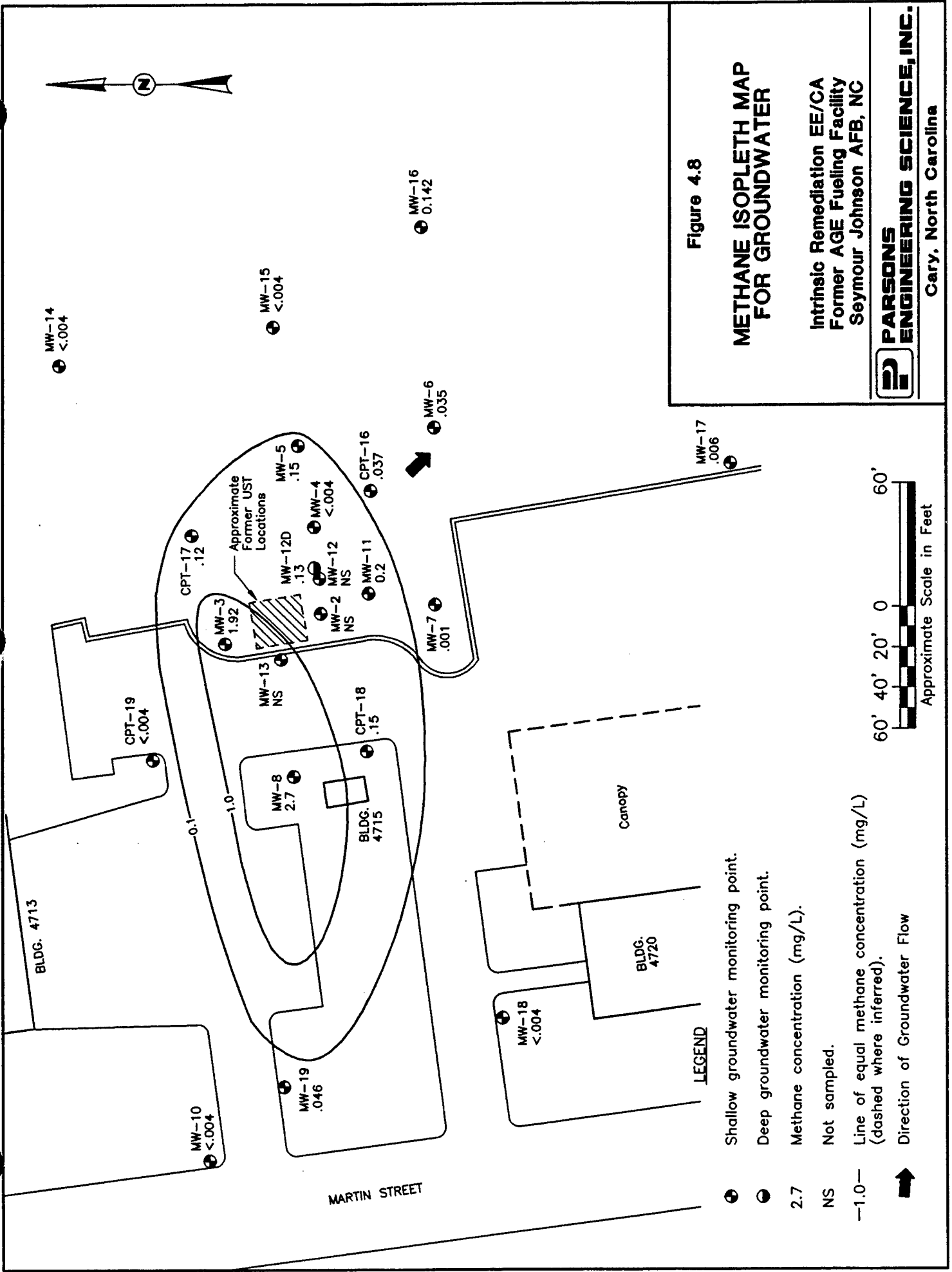
Molecular weights: Benzene $6(12) + 6(1) = 78$ gm/mole

Methane $12 + 4(1) = 16$ gm/mole

Mass ratio of methane to benzene = $3.75(16)/78 = 0.77:1$

Therefore, 0.77 mg of methane is produced during mineralization of 1 mg of benzene.

Similar calculations can be completed for toluene (0.78 mg of methane produced during mineralization of 1 mg of toluene), ethylbenzene (0.79 mg of methane produced during mineralization of 1 mg of ethylbenzene), and the xylenes (0.79 mg of methane produced during mineralization of 1 mg of xylene). The average mass ratio of methane produced during total BTEX mineralization is 0.78:1. This means that approximately 1 mg of BTEX is mineralized for every 0.78 mg of methane produced. The highest measured methane concentration was 2.7 mg/L. This suggests that the shallow groundwater at this site has the capacity to assimilate at least 3.46 mg/L (3,460 µg/L) of total BTEX during methanogenesis. Again, this may be a conservative estimate of the expressed assimilative capacity of methanogenesis because microbial cell mass production is not taken into account by the stoichiometry shown above (see Section 4.4.2.1). In addition, these calculations are based on observed methane concentrations and not the amount of carbon dioxide available in the aquifer. Therefore, methanogenic assimilative capacity could be much higher.



4.4.2.6 Reduction/Oxidation Potential

Redox potentials were measured at groundwater monitoring points at the former AGE fueling facility site. Redox potential is a measure of the relative tendency of a solution to accept or transfer electrons. The redox potential of a groundwater system depends on which electron acceptor is being reduced by microbes during BTEX oxidation. The measured redox potential in groundwater at the site ranges from -93.4 millivolts (mV) to 312 mV. Redox potential data are included in the groundwater geochemical data summary in Table 4.5. Figure 4.9 is an isopleth map that graphically illustrates the distribution of redox potentials measured in groundwater at the site. Redox potential values fall below 100 mV in an area encompassing the most highly contaminated area of the aquifer. In general, areas at the site with low redox potentials coincide with areas of high BTEX contamination, low DO, elevated ferrous iron and methane concentrations, and low sulfate concentrations.

4.4.2.7 Alkalinity

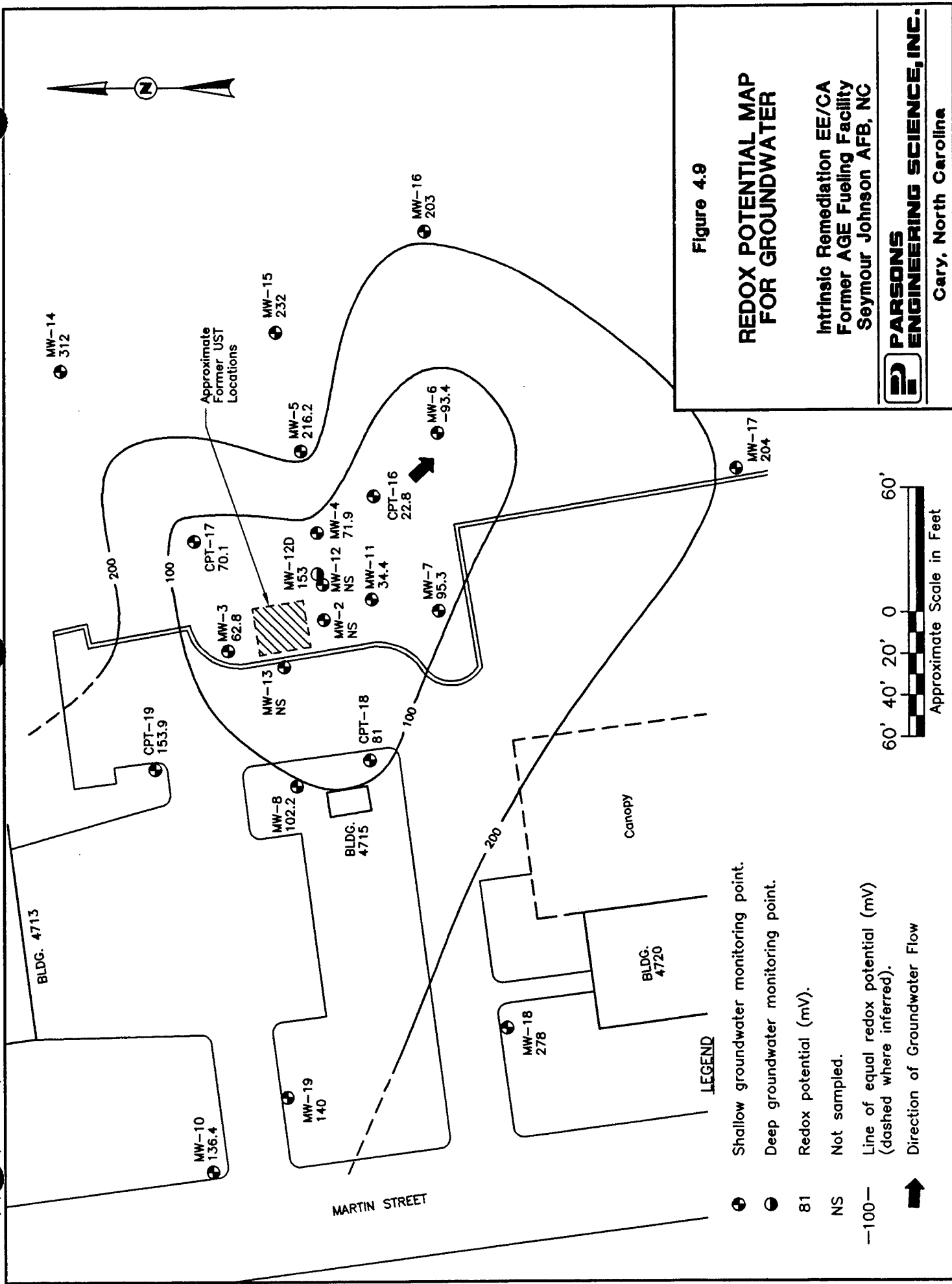
Total alkalinity (expressed as calcium carbonate) was measured in samples from selected groundwater monitoring points at the site. The total alkalinity data are summarized in Table 4.5. Alkalinity is a measure of groundwater's ability to buffer changes in pH, which may be caused by the addition of biologically generated acids. Total alkalinity at the site is in the low to moderate range for groundwater, varying from 10 mg/L to 130 mg/L at MW-3 and MW-11. The ability of groundwater at the site to neutralize acids generated by biodegradation of BTEX may be limited in areas with lower alkalinity levels.

4.4.2.8 pH

Measurements of pH were taken in groundwater monitoring points at the former AGE fueling facility site during the April and July 1995 sampling events. A summary of pH data is included in Table 4.5. The pH of a solution is the negative logarithm of the hydrogen ion concentration $[H^+]$. Groundwater pH at the site ranges from 4.96 (MW-17) to 8.80 (MW-12D) standard units. The majority of groundwater samples had pHs ranging between 5 and 7. This is on the lower end of the acceptable range for BTEX-degrading microbes. pH values lower than 4.5 to 5.5 are generally considered to be less than optimal for BTEX biodegradation. However, the groundwater geochemistry discussed in previous sections of this report suggests that low pH is not inhibiting biodegradation at the site.

4.4.2.9 Temperature

Groundwater temperature was measured at groundwater monitoring points at the site during sample collection. Table 4.5 includes a summary of groundwater temperature data. Temperature affects the types and growth rates of bacteria that can be supported in the groundwater environment, with higher temperatures generally resulting in higher growth rates. Temperatures in the shallow aquifer ranged from 15.1 degrees Celsius ($^{\circ}C$) to 23.0 $^{\circ}C$. Samples from the majority of the monitoring points were collected in April 1995, with the exception of those from MW-14 through MW-19, which were collected in July 1995. The average groundwater temperature in April was 17.4 $^{\circ}C$, while the average in



July was 21.6°C. The range of groundwater temperature at the site is conducive to metabolic activity of BTEX-degrading bacteria.

4.4.3 Expressed Assimilative Capacity

The data presented in the preceding sections suggest that mineralization of BTEX compounds is occurring through the microbially mediated processes of aerobic respiration, denitrification, iron reduction, sulfate reduction, and methanogenesis. Based on the stoichiometry presented in these sections, the expressed BTEX assimilative capacity of groundwater at the former AGE fueling facility site is at least 19.3 mg/L, or 19,300 µg/L (Table 4.6).

A closed system with two liters of water can be used to help visualize the physical meaning of assimilative capacity. Assume that the first liter contains no fuel hydrocarbons, but it contains fuel-degrading microorganisms and has an assimilative capacity of exactly "x" µg of fuel hydrocarbons. The second liter has no assimilative capacity; however, it contains fuel hydrocarbons. As long as these two liters of water are kept separate, biodegradation of the fuel hydrocarbons will not occur. If these two liters are combined in a closed system, biodegradation will commence and continue until the fuel hydrocarbons are depleted, the electron acceptors are depleted, or the environment becomes acutely toxic to the fuel degrading microorganisms. Assuming a non-lethal environment, if more than "x" µg of fuel hydrocarbons were in the second liter of water, only "x" µg of fuel hydrocarbons would ultimately degrade.

The groundwater beneath a site is an open system, which continually receives additional electron receptors through the flow of the aquifer and the percolation of precipitation. This means that the assimilative capacity is not a fixed entity as it is in a closed system, and therefore cannot be compared directly to contaminant concentration in the groundwater. Rather, the expressed assimilative capacity of groundwater is intended to serve as a qualitative tool. Although the expressed assimilative capacity at this site is greater than the highest measured total BTEX concentration (13,800 µg/L), the fate of BTEX in groundwater and the potential impact to receptors is dependent on the relationship between the kinetics of biodegradation and the solute transport velocity (Chapelle, 1994).

This significant expressed assimilative capacity observed in groundwater at the former AGE fueling facility is a strong indicator that biodegradation is occurring; however, it does not ensure that biodegradation will proceed to completion before potential downgradient receptors are impacted. Based on the delineation of the BTEX plume in groundwater at the site, plume migration is being limited and potential downgradient receptors, including surface water bodies, do not appear to be in immediate danger. This was quantitatively evaluated using the Bioplume II model code. Modeling results are presented in Section 5.

TABLE 4.6
EXPRESSED ASSIMILATIVE CAPACITY OF SITE GROUNDWATER
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY SITE
SEYMOUR JOHNSON AFB, NC

Electron Acceptor or Process	Expressed BTEX Assimilative Capacity ($\mu\text{g/L}$)
Dissolved Oxygen	5,820
Denitrification	200
Ferric Hydroxide Reduction	1,450
Sulfate Reduction	8,400
Methanogenesis	3,460
Expressed Assimilative Capacity	19,330
Highest Observed Total BTEX Concentration	13,800

SECTION 5

GROUNDWATER MODELING

5.1 GENERAL OVERVIEW AND MODEL DESCRIPTION

In order to help estimate degradation rates for dissolved BTEX compounds at the former AGE fueling facility site and to help predict the future migration of these compounds, Parsons ES modeled the fate and transport of the dissolved BTEX plume. The modeling effort had three primary objectives: 1) to predict the future extent and concentration of the dissolved contaminant plume by modeling the combined effects of advection, dispersion, sorption, and biodegradation; 2) to assess the potential for downgradient receptors to be exposed to contaminant concentrations above regulatory standards intended to be protective of human health and the environment; and 3) to provide technical support for the natural attenuation remedial option, if appropriate, at post-modeling regulatory negotiations. The model was developed using site-specific data and conservative assumptions about governing physical and chemical processes. Due to the conservative nature of the model input, the reduction in contaminant mass resulting from the process of natural attenuation is expected to exceed model predictions. This analysis is not intended to represent a baseline assessment of potential risks posed by site contamination.

The Bioplume II model was used to estimate the potential for dissolved BTEX migration and degradation by naturally occurring mechanisms operating at the former AGE fueling facility site. The Bioplume II code incorporates advection, dispersion, sorption, and biodegradation to simulate contaminant plume migration and degradation. The model is based upon the USGS Method of Characteristics (MOC) two-dimensional (2-D) solute transport model of Konikow and Bredehoeft (1978). The model code was modified by researchers at Rice University to include a biodegradation component that is activated by a superimposed DO plume. On the basis of the work of Borden and Bedient (1986), the model assumes a reaction between DO and BTEX that is instantaneous relative to the advective groundwater velocity. Bioplume II solves the USGS 2-D solute transport equation twice, once for hydrocarbon concentrations in the aquifer and once for a DO plume. The two plumes are combined using superposition at every particle move to simulate the rapid, biologically-mediated reaction between hydrocarbons and oxygen.

In recent years, it has become apparent that anaerobic processes such as denitrification, iron reduction, sulfate reduction, and methanogenesis can be important BTEX degradation mechanisms (Grbic'-Galic' and Vogel, 1987; Lovley *et al.*, 1989; Grbic'-Galic', 1990; Hutchins, 1991; Beller *et al.*, 1992; Edwards *et al.*, 1992; Edwards and Grbic'-Galic', 1992). As evidenced from the data specified in Section 4, anaerobic biodegradation is occurring at the former AGE fueling facility site. The combined processes of aerobic and anaerobic biodegradation were considered in modeling BTEX fate and transport at the site. As a conservative estimate, oxygen was the only electron acceptor assumed to react instantaneously relative to the solute velocity. The following

subsections discuss in detail the input parameters, the model assumptions, the model calibration, and simulation results.

One-dimensional analytical models based on the works of Bear (1979) and vanGenuchten and Alves (1982) were used during the modeling effort. The models incorporate advection, dispersion, retardation, and first-order decay in order to simulate one-dimensional contaminant fate and transport. Analytical models were first used to screen potential value ranges for select parameters prior to incorporation into the Bioplume II model. Afterwards, analytical model results were used for comparison to calibrated and predictive Bioplume II models to help confirm the results of the numerical models. Analytical model results are presented in Appendix E.

5.2 CONCEPTUAL MODEL DESIGN AND ASSUMPTIONS

Prior to developing a groundwater model, it is important to determine if sufficient data are available to provide a reasonable estimate of aquifer conditions. In addition, it is important to ensure that any limiting assumptions can be justified. The most important assumption made when using the Bioplume II model is that oxygen-limited biodegradation is occurring at the site. The Bioplume II model assumes that the limiting factors for biodegradation are: 1) the presence of an indigenous hydrocarbon-degrading microbial population, and 2) sufficient background electron acceptor concentrations. Data and information presented in Sections 3 and 4 suggest that oxygen, nitrate, ferric hydroxide, sulfate, and carbon dioxide (methanogenesis) are being used as electron acceptors for aerobic and anaerobic biodegradation.

Based on the data presented in Section 3, the shallow saturated zone was conceptualized and modeled as a thin, shallow, unconfined to semiconfined aquifer composed of silty sand (Figures 3.2, 3.3, and 3.4). The use of a 2-D model is appropriate at the former AGE fueling facility site because the saturated interval is thin and relatively homogenous. In addition, the clay that forms the bottom confining layer of the surficial aquifer is much less transmissive than the surficial aquifer and will limit vertical migration of dissolved BTEX.

BTEX is known to emanate from the mobile LNAPL contamination and the residual soil contamination as a result of fuels storage (JP-4, gasoline, and diesel fuel), distribution leaks, and spills during fueling operations. Contaminated soils at the site have not been remediated, although the three USTs and related infrastructure have been removed. In addition, the Base has been implementing LNAPL removal by manually bailing MW-13 weekly. No additional fuel releases are expected at the site, and only BTEX leaching from the mobile and residual LNAPL contamination at the site was considered as a continuing source for the dissolution of BTEX into groundwater over time.

5.3 INITIAL MODEL SETUP

Where possible, the initial setup for this model was based on site data. Where site-specific data were not available (e.g., effective porosity, reaeration coefficient),

reasonable assumptions for the types of materials comprising the shallow aquifer were made based on widely accepted literature values. The following sections describe the basic model setup and calibration. Following calibration, a sensitivity analysis was performed by varying the input parameters known to have the most significant effect on model results. Those Bioplume II model parameters that were varied during model calibration are discussed in Section 5.4.2.1.

5.3.1 Grid Design and Boundary Conditions

The maximum grid size for the Bioplume II model is limited to 20 columns by 30 rows and the dimension of each column and row can range from 0.1 to 999.9 feet. A grid size of 20 cells (transverse or y-direction) by 30 cells (longitudinal or x-direction) was used to model the former AGE fueling facility site. The grid was oriented so that the positive x-axis was parallel to the overall direction of groundwater flow. Each grid cell was 30 feet wide by 50 feet long. The model grid covers an area of 900,000 square feet, or approximately 21 acres. The full extent of the model grid is indicated on Figure 5.1.

Model boundaries are mathematical statements that represent hydrogeologic boundaries, such as areas of specified head (e.g., surface water bodies or contour lines of constant hydraulic head) or specified flux. Hydrogeologic boundaries are represented by three mathematical statements that describe the hydraulic head at the model boundaries. These include:

- 1) Specified-head boundaries (Dirichlet condition) for which the head is determined as a function of location and time only. Surface water bodies exhibit constant-head conditions. Specified-head boundaries are expressed mathematically as:

$$\text{Head} = f(x, y, z, t)$$

where f is the function symbol, x , y , and z are position coordinates, and t is time.

- 2) Specified-flow boundaries (Neumann conditions) for which the mathematical description of the flux across the boundary is given. The flux is defined as a volumetric flow rate per unit area (e.g., $\text{ft}^3/\text{ft}^2/\text{day}$). No-flow boundaries are a special type of specified-flow boundary and are set by specifying the flux to be zero. Examples of no-flow boundaries include groundwater divides and impermeable hydrostratigraphic units. Specified-flux boundaries are expressed mathematically as:

$$\text{Flux} = f(x, y, z, t)$$

- 3) Head-dependent flow boundaries (Cauchy or mixed boundary conditions) where the flux across the boundary is calculated from a given boundary head value. This type of flow boundary is sometimes referred to as a mixed-boundary condition because it is a combination of a specified-head boundary and a specified-flow boundary. Head-dependent flow boundaries are used to model

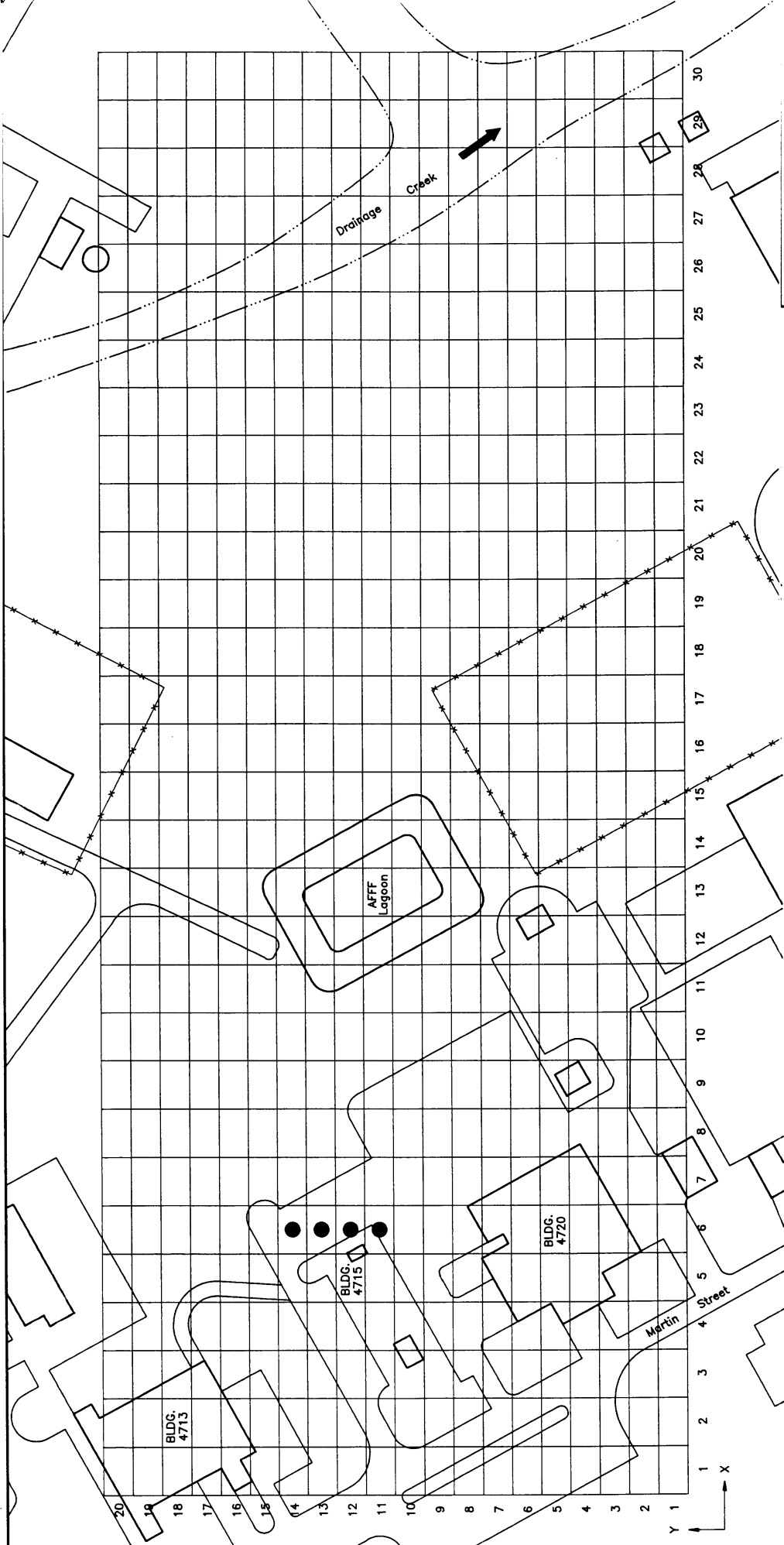
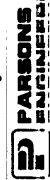


Figure 5.1

MODEL GRID

Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC



Cary, North Carolina



LEGEND
Location of simulated BTEX injection well.



leakage across semipermeable boundaries. Head-dependent flow boundaries are expressed mathematically as (Bear, 1979):

$$\text{Flux} = (H_o - H)K'/B'$$

Where: H = Head in the zone being modeled (generally the zone containing the contaminant plume)
 H_o = Head in external zone (separated from plume by semipermeable layer)
 K' = Hydraulic conductivity of semipermeable layer
 B' = Thickness of semipermeable layer.

Natural hydraulic boundaries are modeled using a combination of the three types of model boundary conditions listed above. When possible, hydrologic boundaries such as surface water bodies, groundwater divides, contour lines, or hydrologic barriers should coincide with the perimeter of the model. In areas lacking obvious hydrologic boundaries, specified-head or specified-flux boundaries can be specified at the model perimeter if the boundaries are far enough removed from the contaminant plume that transport calculations are not affected. Bioplume II requires the entire model domain to be bounded by zero-flux cells (also known as no-flow cells), with other boundary conditions established within the subdomain specified by the no-flow cells.

Specified-head boundaries for the model were set on the northwestern perimeter of the model grid to simulate the primary southeasterly groundwater flow direction at the site. These heads were set at the approximate location of the water table indicated by July 1995 water level data. An estimated head of 87 feet above msl was used along the northwestern boundary (upgradient), based on observed groundwater elevations in MW-10, MW-18, and MW-19 (Figure 3.5).

The downgradient specified-head boundary was set in the model cells through which the drainage creek runs (see Figure 5.1). Parsons ES utilized the drainage creek as the downgradient model boundary due to its potential influence on contaminant plume migration. The head at the downgradient model boundary was approximated using the USGS (1982) topographic map (Southeast Goldsboro, NC). Using the topographic contours that border the creek, the head along the length of the creek at the downgradient boundary was set at 82 feet msl. Due to the lack of site-specific data from this area, the downgradient model boundary head was assumed to be constant.

The northeastern and southwestern (lateral) model boundaries were configured as no-flow (specified flux) boundaries. Flux through these boundaries is assumed to be zero because flow is generally parallel to these boundaries.

The local-scale hydraulics at the former AGE fueling facility site are fairly complicated because the actual site conditions reflect areas of differential recharge to shallow groundwater (e.g. asphalt, concrete, and buildings versus natural vegetated areas and landscaped areas). The effects of differential recharge create additional lateral plume migration pathways on a local scale. To simplify the model, these lateral migration pathways were not included within the calibrated model.

5.3.2 Groundwater Elevation and Gradient

The water table elevation map presented in Figure 3.5 was used to define the starting heads for input into the Bioplume II model. Groundwater flow in the vicinity of the former AGE fueling facility site is to the southeast with an average gradient of approximately 0.005 ft/ft (see Section 3.3.2.1). Three separate rounds of water level measurements were taken to characterize the water table surface at the site. Very minor differences in the water table surface elevations were noted. Parsons ES chose a location for the upgradient model boundary approximately 250 feet upgradient from the contaminant source area. As described in Section 5.4.1, the model was calibrated to the July 1995 observed water table.

5.3.3 BTEX Concentrations

The total dissolved BTEX concentrations obtained from laboratory analytical results for each monitoring point location were used for model development. At each monitoring point, the highest BTEX concentration observed at that location was used as the representative concentration. Table 4.2 presents dissolved BTEX concentration data. Figure 4.3 shows the spatial distribution of dissolved BTEX compounds in groundwater at the site.

The BTEX plume observed at the former AGE fueling facility site suggests that the primary migration pathway is toward the southeast. The plume appears to have spread laterally relative to the downgradient direction (i.e., to the northeast, southwest, and west). Slightly mounded groundwater in the area of the release (see Figure 3.5) has facilitated this lateral migration of the BTEX plume. The shape and distribution of the total BTEX plume is the result of the release location with respect to the areas of differential recharge, as well as advective-dispersive transport, sorption, and biodegradation of dissolved BTEX contamination. The plume covers an area of approximately 24,800 square feet (0.57 acre). As described in Section 5.4.2, the simulated BTEX plume was calibrated to closely approximate the observed BTEX plume along the primary (southeasterly) flow path.

5.3.4 Electron Acceptors (Dissolved Oxygen)

As discussed previously, the Bioplume II model assumes an instantaneous reaction between the BTEX plume and the DO plume. The discussion presented in Section 4 suggests that DO, nitrate, ferric iron, carbon dioxide, and sulfate are being used as electron acceptors for biodegradation of BTEX compounds at the former AGE fueling facility site. To be conservative, the total BTEX plume at the site was modeled assuming that DO was the only electron acceptor being utilized for the biodegradation of BTEX compounds at a rate that is instantaneous relative to the advective groundwater flow velocity.

Two groundwater samples collected in uncontaminated portions of the aquifer suggest that the background DO concentration at the site may be as high as 9.06 mg/L (CPT-19) or 8.25 mg/L (MW-10). Background oxygen levels were conservatively assumed to be

8.0 mg/L for Bioplume II model development. This concentration was applied as an input at upgradient specified-head boundary cells. Table 4.5 presents DO data for the site. Figure 4.4 is the DO isopleth map for the site. Gridded oxygen input data are included in Appendix C.

5.3.5 Anaerobic Degradation Rates

Available data strongly suggest that anaerobic degradation is occurring at the site. Combined anaerobic processes account for over 70 percent of the assimilative capacity of site groundwater (Table 4.6). Anaerobic degradation must therefore be simulated with Bioplume II to make meaningful predictions. The Bioplume II model simulates anaerobic biodegradation by assuming that such degradation follows first-order kinetics. As with a large number of biological processes, anaerobic biodegradation can generally be described using a first-order rate constant and the equation:

$$\frac{C}{C_o} = e^{-kt}$$

Where: C = Contaminant Concentration at Time t ;
 C_o = Initial Contaminant Concentration;
 k = Coefficient of Anaerobic Decay (anaerobic rate constant);
 and
 t = time.

Two methods of calculating the anaerobic rate constant are currently available to quantify rates of biodegradation at the field scale and are applicable for use with available site data. The first method involves the use of a biologically recalcitrant compound found in the dissolved BTEX plume that can be used as a conservative tracer. The second method, proposed by Buscheck and Alcantar (1995) involves interpretation of a steady-state contaminant plume configuration and is based on the one-dimensional steady-state analytical solution to the advection-dispersion equation presented by Bear (1979).

5.3.5.1 Trimethylbenzene Tracer Method

In order to calculate first-order decay rate constants in the anaerobic core of the plume, the apparent degradation rate must be normalized for the effects of dilution caused by advective-dispersive processes. This is accomplished by normalizing the concentration of each contaminant to the concentration of a component of fuel (a tracer) that has similar sorptive properties but that is fairly recalcitrant. Observed concentration data can be normalized to 1,3,5-TMB, 1,2,4-TMB, and 1,2,3-TMB or another tracer with similar physiochemical properties. The TMB isomers serve as good tracers because they can be recalcitrant to microbial biodegradation under anaerobic conditions, and have sorptive properties similar to the BTEX compounds (Cozzarelli et al., 1990 and 1994). Thus, these compounds are assumed to respond similarly to the processes of advection, dispersion and sorption without experiencing a reduction in concentration due to biodegradation.

The corrected concentration of a compound is the concentration of the compound that would be expected at one point (B) located downgradient from another point (A) after correcting for the effects of dispersion, dilution, and sorption between points A and B. One relationship that can be used to calculate the corrected contaminant concentration is:

$$C_{B,Corr} = C_B(TMB_A/TMB_B)$$

Where: $C_{B,Corr}$ = Corrected concentration of compound at Point B;
 C_B = Measured concentration of compound at Point B;
 TMB_A = Measured TMB concentration at Point A; and
 TMB_B = Measured TMB concentration at Point B.

A log-linear plot of the corrected contaminant concentrations versus the travel time from the origin can be used to determine whether the data set can be described using a first-order exponential equation [i.e., the coefficient of determination (R^2) is greater than approximately 0.9]. When this occurs, the exponential slope can be used as the anaerobic rate constant.

First-order decay constants were calculated based on BTEX and TMB data from the site (presented in Table 4.2). Rate constant calculations are included in Appendix E. Calculated rate constants for the former AGE fueling facility site ranged from 0.0004 to 0.0251 week⁻¹ (0.0001 to 0.0036 day⁻¹) along the primary southeasterly flow path.

5.3.5.2 Method of Buscheck and Alcantar

Buscheck and Alcantar (1995) derive a relationship that allows calculation of first-order decay rate constants for steady-state plumes. This method involves coupling the regression of contaminant concentration (plotted on a logarithmic scale) versus distance downgradient (plotted on a linear scale) to an analytical solution for one-dimensional, steady-state, contaminant transport that includes advection, dispersion, sorption, and biodegradation. For a steady-state plume, the first-order decay rate is given by (Buscheck and Alcantar, 1995):

$$\lambda = \frac{v_c}{4\alpha_x} \left(\left[1 + 2\alpha_x \left(\frac{k}{v_x} \right) \right]^2 - 1 \right)$$

Where: λ = first-order decay rate;
 v_c = retarded contaminant velocity in the x-direction;
 α_x = dispersivity; and
 k/v_x = slope of line determined from a log-linear plot of contaminant concentration versus distance downgradient along flow path.

The first-order decay rate includes biodegradation resulting from both aerobic and anaerobic processes; however, in the absence of oxygen, the first-order rate is equivalent to the anaerobic decay rate. Appendix E presents a first-order rate constant calculation for BTEX using 1995 data at the site and the method proposed by Buscheck and Alcantar (1995). An exponential fit to the data estimates an average log-linear slope of -0.0435 feet⁻¹, which was in turn used to estimate an average decay constant of

0.0018 day⁻¹ (0.013 week⁻¹). The loss of BTEX along this flow path closely approximates a first-order biodegradation decay rate, with an average calculated R² of 0.952.

5.3.5.3 Selection of Anaerobic Decay Rate Constant

A review of recent literature indicates that higher anaerobic rate constants generally have been calculated at other sites. For example, Chapelle (1994) reported that at two different sites with anaerobic groundwater conditions, the anaerobic rate constants were both approximately 0.01 day⁻¹. Wilson *et al.* (1994) reported first-order anaerobic biodegradation rates of 0.05 to 1.3 week⁻¹ (0.007 to 0.185 day⁻¹); Buscheck *et al.* (1993) report first-order attenuation rates in the range of 0.001 to 0.01 day⁻¹; and Stauffer *et al.* (1994) report rate constants of 0.01 and 0.018 day⁻¹ for benzene and *p*-xylene, respectively. An initial anaerobic rate constant of 0.003 day⁻¹ was used in Bioplume II model for this site. This value was selected based on the values estimated by the method of Buscheck and Alcantar (1995) and the values estimated from TMB normalization. Furthermore, an anaerobic decay constant of 0.003 day⁻¹ day is at the low end of the range of values reported in the literature. Therefore, this selected biodegradation rate is potentially conservative.

5.4 MODEL CALIBRATION

Model calibration is an important component in the development of any numerical groundwater model. Calibration of the flow model demonstrates that the model is capable of matching hydraulic conditions observed at the site; calibration of a contaminant transport model superimposed upon the calibrated flow model helps verify that contaminant loading and transport conditions are being appropriately simulated. The numerical flow model presented herein was calibrated by altering transmissivity until simulated heads approximated observed field values within a prescribed accuracy. After calibration of the flow component, the numerical transport model was calibrated by altering hydraulic and transport parameters until the simulated BTEX plume approximated observed field values. Table 5.1 lists input parameters used for the modeling effort. Model input and output are included in Appendix C.

5.4.1 Water Table Calibration

The shallow water table at the former AGE fueling facility site was assumed to be influenced only by continuous recharge and discharge at the constant-head cells established at the upgradient and downgradient model boundaries. The water levels observed at the site during July 1995 were utilized as input for the upgradient constant-head cells. To be conservative, recharge of the aquifer through rainfall (which would add water and DO, thereby increasing dilution and biodegradation of the plume) was not included in the model. Potential recharge at infiltration zones and other water sources was omitted because of a lack of reliable data during non-steady conditions. Only the transmissivity values were varied to calibrate the water table surface. The model was calibrated under steady-state conditions.

TABLE 5.1
BIOPLUME II MODEL INPUT PARAMETERS
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY SITE
SEYMOUR JOHNSON AFB, NC

Parameter	Description	SETUP16 Calibrated Model Setup	SR5	SR3
NTIM	Max. number of time steps in a pumping period	1	1	1
NPMP	Number of Pumping Periods	1	10	8
NX	Number of nodes in the X direction	20	20	20
NY	Number of nodes in the Y direction	30	30	30
NPMAX	Maximum number of Particles NPMAX = (NX-2)(NY-2)(NPTPND) + (N _s ^{a/})(NPTPND) + 250	4966	4966	4966
NPNT	Time step interval for printing data	1	1	1
NITP	Number of iteration parameters	7	7	7
NUMOBS	Number of observation points	0	0	0
ITMAX	Maximum allowable number of iterations in ADIP ^{b/}	200	200	200
NREC	Number of pumping or injection wells	4	4	4
NPTPND	Initial number of particles per node	9	9	9
NCODES	Number of node identification codes	2	2	2
NPNTMV	Particle movement interval (IMOV)	0	0	0
NPNTVL	Option for printing computed velocities	0	0	0
NPNTD	Option to print computed dispersion equation coefficients	0	0	0
NPDELC	Option to print computed changes in concentration	0	0	0
NPNCHV	Option to punch velocity data	0	0	0
NREACT	Option for biodegradation, retardation and decay	1	1	1
PINT	Pumping period (years)	10	10	10
TOL	Convergence criteria in ADIP	0.001	0.001	0.001
POROS	Effective porosity	0.3	0.3	0.3
BETA	Characteristic length (long. dispersivity; feet)	8	8	8
S	Storage Coefficient	0 (Steady- State)	0	0
TIMX	Time increment multiplier for transient flow	NA ^{c/}	NA	NA
TINIT	Size of initial time step (seconds)	NA	NA	NA
XDEL	Width of finite difference cell in the x direction (feet)	30	30	30
YDEL	Width of finite difference cell in the y direction (feet)	50	50	50
DLTRAT	Ratio of transverse to longitudinal dispersivity	0.1	0.1	0.1
CELDIS	Maximum cell distance per particle move	0.5	0.5	0.5
ANFCTR	Ratio of Tyy to Txx	1 (Isotropic)	1	1
DK	Distribution coefficient	0.1738	0.1738	0.1738
RHOB	Bulk density of the solid (grams/cubic centimeter)	1.6	1.6	1.6
THALF	Half-life of the solute	0	0	0
DEC1	Anaerobic decay coefficient	0.0035	0.0035	0.0035
DEC2	Reaeration coefficient (day ⁻¹)	0	0	0
F	Stoichiometric Ratio of Hydrocarbon to Oxygen	3.1	3.1	3.1

^{a/} N_s = Number of nodes which represent fluid sources

^{b/} ADIP = Alternating - direction implicit procedure (subroutine for solving groundwater flow equation)

^{c/} NA = Not applicable

Transmissivity is the product of the hydraulic conductivity and the thickness of the aquifer. Hydraulic conductivity is an important aquifer characteristic that determines the ability of the water-bearing strata to transmit groundwater. An accurate estimate of hydraulic conductivity is important to help quantify advective groundwater flow velocities and to define the flushing potential of the aquifer and the quantity of electron-acceptor-charged groundwater that is entering the site from upgradient locations. As indicated by the work of Rifai *et al.* (1988), the Bioplume II model is particularly sensitive to variations in hydraulic conductivity. Lower values of hydraulic conductivity result in a slower-moving plume with a relatively small areal extent and higher average BTEX concentration. Higher values of hydraulic conductivity result in a faster-moving plume that is spread over a larger area and contains lower average BTEX concentrations.

Saturated thickness data from previous reports, geologic logs, and water level measurements were used in conjunction with the average hydraulic conductivity [1.74×10^{-4} feet per second (ft/sec)(15 ft/day)] to estimate an initial uniform transmissivity for the entire model domain. In order to better simulate estimated contaminant and groundwater velocities, the hydraulic conductivity was reduced to approximately one-half of the average reported hydraulic conductivity (9.25×10^{-5} ft/sec or 8 ft/day). This K value is within the range of values calculated for the shallow aquifer at Seymour Johnson AFB.

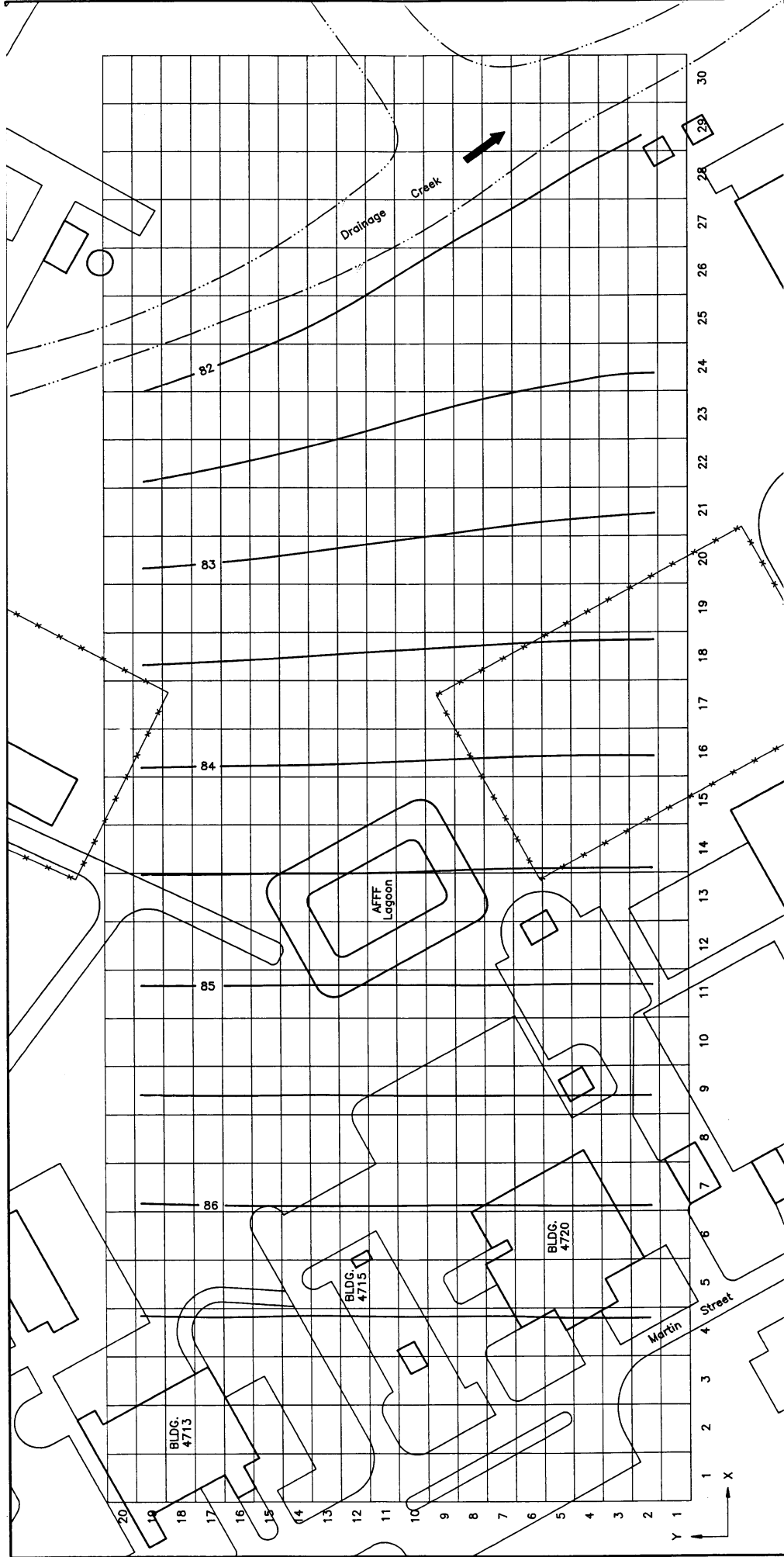
The calibrated hydraulic model predicted site hydraulic gradients comparable to those observed in the field. As noted in Section 3, the measured hydraulic gradient at the former AGE fueling facility site was 0.005 ft/ft. This matches well with the overall hydraulic gradient from the upgradient site boundary to the downgradient drainage creek (0.004 ft/ft). Figure 5.2 shows the calibrated water table. As noted before, only the southeastern component of flow at the site was considered for the model.

Water level elevation data from cells associated with 16 monitoring points also were used to compare the calibrated model to observed data. The 16 selected cell locations each contain one of the following monitoring points: MW-3, MW-4, MW-5, MW-6, MW-7, MW-8, MW-11, MW-14, MW-15, MW-16, MW-17, MW-18, MW-19, CPT-16, CPT-17, and CPT-18. The root mean squared (RMS) error is commonly used to express the average difference between simulated and measured water level elevations. The RMS error is the average of the squared differences between measured and simulated heads, and can be expressed as:

$$\text{RMS} = \left[\frac{1}{n} \cdot \sum_{i=1}^n \left[h_m - h_s \right]^2 \right]^{0.5}$$

Where: n = the number of points where heads are being compared;
 h_m = measured head value; and
 h_s = simulated head value.

The RMS error between observed and calibrated values at the 16 comparison points was 0.57 foot over the domain of the test well population. This corresponds to a calibration error of 11.4 percent (water levels dropped a maximum of 5 feet over the



LEGEND

—85— Water table surface contour (feet above mean sea level).

Figure 5.2

CALIBRATED WATER TABLE MAP

Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC



**PARSONS
ENGINEERING SCIENCE, INC.**
Gary, North Carolina

length of the model grid). RMS error calculations are summarized in Appendix C. A plot of measured versus calibrated heads shows a random distribution of points around a straight line, as shown in Appendix C. Deviation of points from a straight line should be randomly distributed in a plot of results from computer simulations (Anderson and Woessner, 1992).

In solving the groundwater flow equation, Bioplume II establishes the water table surface and calculates an overall hydraulic balance that accounts for the numerical difference between flux into and out of the system. The hydraulic mass balance for the calibrated model was excellent, with 99.9 percent of the water flux into and out of the system being numerically accounted for (i.e., a 0.1-percent error). According to Anderson and Woessner (1992), a mass balance error of around 1 percent is acceptable, while Konikow (1978) indicates an error of less than 0.1 percent is ideal.

5.4.2 BTEX Plume Calibration

Model input parameters affecting the distribution and concentration of the simulated BTEX plume were modified so that model predictions matched dissolved total BTEX concentrations observed at the site in April 1995. To do this, model runs were made using the calibrated steady-state hydraulic parameters coupled with the introduction of contaminants. The fuel release was originally noted at the site in 1994; however, the exact release date and the number of past releases is unknown. Considering the plume configuration in relation to the source area and accounting for advection and plume retardation, the time required to form the plume observed in 1995 may have ranged from 5 to 15 years. A formation time of 10 years was assumed for model calibration. Therefore, the computed BTEX plume concentrations and configurations were compared to 1995 data after 10 years of simulation time incorporating the introduction of contaminants into the groundwater.

Estimated BTEX source concentrations were applied to four simulated injection wells to reproduce the configuration and concentrations of the southeastern portion of the groundwater BTEX plume. It was necessary to include model injection wells to simulate continuing partitioning of BTEX compounds into the groundwater from mobile and residual LNAPL present in the vicinity of the water table at the site. While the term "injection well" suggests contaminants are being introduced at a point, Bioplume II assumes that contamination introduced at a well instantly equilibrates throughout the entire cell in which the well is located. The injection rate for the cells was set at 1.0×10^{-6} cubic foot per second (ft^3/sec), a value low enough so that the flow calibration and water balance was not affected. Locations and numbers of injection wells (Figure 5.1) were selected on the basis of the known extent of mobile and residual LNAPL (see Figures 4.1 and 4.2) and their ability to reproduce the observed extent of the dissolved BTEX plume. Total BTEX mass loading rates were determined by varying the injection well concentrations until the modeled total BTEX plume approximated the total BTEX plume observed in 1995.

The calibrated model plume, while not identical to the observed BTEX plume, is a suitable approximation for the purposes of this demonstration in terms of migration

distance and BTEX concentrations in the source area. The calibrated plume configuration is shown on Figure 5.3. Differences in modeled and actual plume shapes and concentrations are caused by physical, chemical, and biological variations within the shallow saturated zone that result from natural aquifer heterogeneity, as well as the use of the model to simulate a portion of the plume.

The downgradient extent of the computed 10- $\mu\text{g/L}$, 100- $\mu\text{g/L}$, 1,000- $\mu\text{g/L}$, and 10,000- $\mu\text{g/L}$ contours (Figure 5.3) are similar to the respective contours observed in 1995 (Figure 4.3) along the primary (southeasterly) flow direction. The widths of the computed 1,000- $\mu\text{g/L}$ and 10,000- $\mu\text{g/L}$ contours are slightly greater than the observed contours. Due to the additional mass added to the system, this difference is conservative. In addition, the apparent slight upgradient spread of the BTEX plume observed in 1995 was not reproduced by the model. This difference is the result of the divergent flow field in the vicinity of the source area, which is not accounted for in the steady-state numerical model.

The computed plume does not predict BTEX concentrations as high as the concentration observed in MW-4 (13,800 $\mu\text{g/L}$). The maximum simulated concentration of 11,506 $\mu\text{g/L}$ was located in a cell just upgradient from the location of MW-4. This difference is acceptable because the 11,506 $\mu\text{g/L}$ concentration represents an average concentration for the entire cell; however, the 13,800 $\mu\text{g/L}$ concentration represents a maximum concentration detected at one point. Other samples collected in the immediate vicinity of the source area, contained dissolved BTEX concentrations below 9,000 $\mu\text{g/L}$. Total BTEX concentrations in excess of the predicted solubility limit were detected in LNAPL samples and source area samples containing emulsified LNAPL. During model calibration, this area was modeled as the area of contaminant injection.

5.4.2.1 Discussion of Parameters Varied During Plume Calibration

The transport parameters varied during plume calibration were dispersivity, the coefficient of retardation, the anaerobic decay coefficient, and the hydraulic conductivity. Varying transport parameters such as the retardation factor and the longitudinal dispersivity within reasonable ranges did not affect the plume length substantially. In general, transport parameters were varied with the intent of altering plume migration so that the observed plume extent was reproduced. While these parameters were varied with this common intent, each had a slightly different impact on the size and shape of the simulated plume.

5.4.2.1.1 Dispersivity

Much controversy surrounds the concepts of dispersion and dispersivity. Longitudinal dispersivity values are typically considered to be scale dependent. In other words, for a given sediment type, dispersivity values will depend upon the distance traveled by the solute. Gelhar *et al.* (1985) performed a critical review of various field experiments and found that longitudinal dispersivities varied from 0.03 foot to 18,000 feet. Longitudinal dispersivity at the site was originally estimated as 8.2 feet, using one-tenth (0.1) of the distance between center of the source area and the longitudinal centroid of the 1995

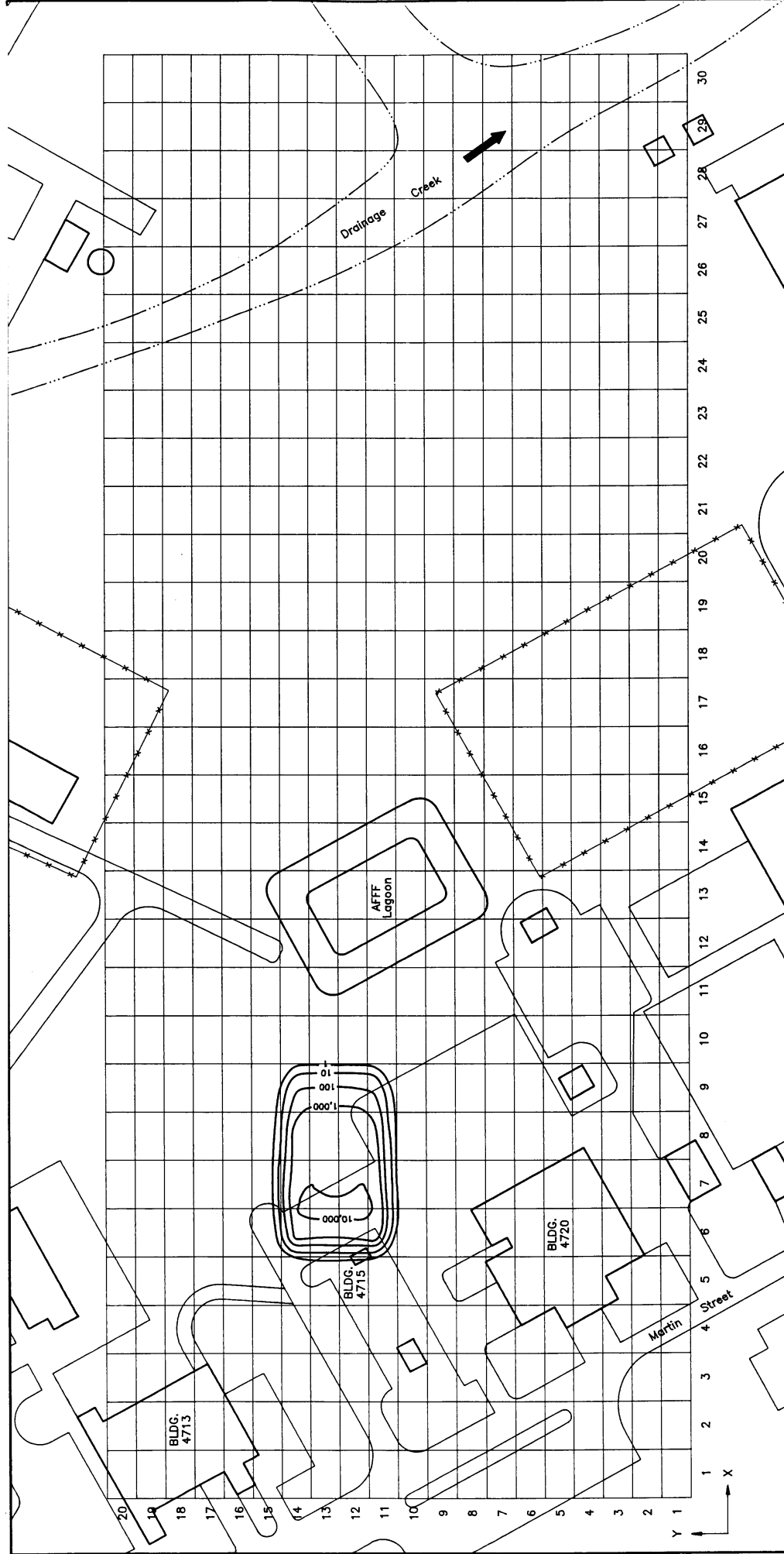


Figure 5.3

CALIBRATED BTEX DISTRIBUTION FOR 1996

Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC



plume (see Figure 4.3). Dispersivity estimation calculations are included in Appendix C. Transverse dispersivity values generally are estimated as one-tenth (0.1) of the longitudinal dispersivity values (Domenico and Schwartz, 1990).

During plume calibration, longitudinal dispersivity was maintained at 8 feet. This value is low compared to possible values in the literature (Walton, 1988). The use of low dispersivity values is a conservative estimate for modeling because low dispersivities cause less BTEX to be lost to dilution. At the same time, the ratio of transverse dispersivity to longitudinal dispersivity was maintained at 0.1 to help reproduce the plume width observed at the site.

5.4.2.1.2 Coefficient of Retardation

Retardation of the BTEX compounds relative to the advective velocity of the groundwater occurs when BTEX molecules are sorbed to the aquifer matrix. The coefficients of retardation (R) for the BTEX compounds were calculated based on measured TOC concentrations in the soils in and near the saturated zone at the site, an assumed bulk density of 1.6 grams/cubic centimeter (Freeze and Cherry, 1979), and published values of the soil sorption coefficient (K_{oc}) for the BTEX compounds, as listed by Wiedemeier *et al.* (1995). The results of these calculations are summarized in Table 5.2.

Typically, the minimum retardation coefficient is used as a conservative assumption. The lower the assumed coefficient of retardation, the farther the BTEX plume will migrate downgradient. However, the minimum fraction organic carbon measured for the site was below the reportable method detection limit. Therefore, the average retardation coefficient calculated for the BTEX compounds ($R=1.93$) was used for initial model input. Because this value is relatively low for soils of this origin, this retardation coefficient is still conservative. During plume calibration, the coefficient of retardation gradually was raised from the initial value of 1.93 to a value of 19.3 and also decreased to a value of 1 (no retardation). This analysis suggested that the initial retardation coefficient ($R = 1.93$) adequately describes sorption of the BTEX plume. As a result, this value was used in the final model simulations.

5.4.2.1.3 Anaerobic Decay Coefficient

The coefficient of anaerobic decay is a first-order rate constant used in Bioplume II to simulate the rate of use and replenishment of anaerobic electron acceptors in the groundwater. A coefficient of 0.0018 day^{-1} (0.0126 week^{-1}) was estimated based on the method of Buscheck and Alcantar (1995). Using the TMB tracer method, first-order decay ranged from 0.0004 week^{-1} (0.00006 day^{-1}) to 0.025 week^{-1} (0.0036 day^{-1}). Use of a first-order anaerobic decay coefficient is justified at this site because anaerobic decay mechanisms account for 70 percent of the assimilative capacity at the site and because the loss of BTEX compounds at the site closely approximates a first-order decay (Section 5.3.4.2). The coefficient of anaerobic decay had a significant effect on limiting plume

TABLE 5.2
CALCULATION OF RETARDATION COEFFICIENTS
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY SITE
SEYMOUR JOHNSON AFB, NORTH CAROLINA

Compound	K_{oc} (L/kg ^{a/})	Fraction Organic Carbon ^{b/}			Distribution Coefficient K_d (L/kg)			Bulk Density (L/kg) ^{d/}	Effective Porosity ^{d/}	Coefficient of Retardation		
		Maximum	Minimum	Average	Maximum ^{c1/}	Minimum ^{c2/}	Average ^{c3/}			Maximum	Minimum	Average
Benzene	79	0.0048	6.00E-04	0.00220	0.379	0.0474	0.1738	1.60	0.30	3.02	1.25	1.93
Toluene	190	0.0048	6.00E-04	0.00220	0.912	0.1140	0.418	1.60	0.30	5.86	1.61	3.23
Ethylbenzene	468	0.0048	6.00E-04	0.00220	2.246	0.2808	1.030	1.60	0.30	12.98	2.50	6.49
m-Xylene	405	0.0048	6.00E-04	0.00220	1.944	0.2430	0.891	1.60	0.30	11.37	2.30	5.75
o-Xylene	422	0.0048	6.00E-04	0.00220	2.026	0.2532	0.928	1.60	0.30	11.80	2.35	5.95
p-Xylene	357	0.0048	6.00E-04	0.00220	1.714	0.2142	0.785	1.60	0.30	10.14	2.14	5.19

NOTES:

^{a/} From technical protocol (Wiedemeier *et al.*, 1995).

^{b/} From site data in noncontaminated area (see Section 4.2.3).

^{c1/} K_d = Maximum Fraction Organic Carbon x K_{oc} .

^{c2/} K_d = Minimum Fraction Organic Carbon x K_{oc} .

^{c3/} K_d = Average Fraction Organic Carbon x K_{oc} .

^{d/} Literature values.

migration, and was also important in controlling the concentrations at the fringes of the plume.

During plume calibration, the anaerobic decay coefficient was varied from an initial value of 0.003 day^{-1} (0.021 week^{-1}) to values between 0.0 day^{-1} and 0.006 day^{-1} (0.042 week^{-1}). A final value of 0.0035 day^{-1} (0.024 week^{-1}) best reproduced the BTEX plume observed in 1995. This analysis suggests that an anaerobic decay coefficient near the upper end of the calculated range most adequately describes the formation of the present-day BTEX plume. As a result, this value was used in the final model simulations.

5.5 SENSITIVITY ANALYSIS

The purpose of the sensitivity analysis is to determine the effect of varying model input parameters on model output. Based on the work of Rifai *et al.* (1988), the Bioplume II model is most sensitive to changes in the coefficient of reaeration, the coefficient of anaerobic decay, and the hydraulic conductivity of the media; and is less sensitive to changes in the retardation factor, porosity, and dispersivity. Because of their relative impact on the Bioplume II model, sensitivity analyses were performed by varying both the hydraulic conductivity and the coefficient of anaerobic decay. The reaeration coefficient was not used; therefore, an analysis of this parameter was not performed. As a result of large theoretical ranges of potential values, sensitivity analyses also were performed for dispersivity and the retardation coefficient.

To perform the sensitivity analyses, the calibrated model was adjusted by systematically changing the aforementioned parameters individually, and then comparing the new model runs to the original calibrated model. The sensitivity models were run for a 10-year period (the same duration used to achieve calibration in the original calibrated model) to assess each variable's effect independently. As a result, eight sensitivity runs of the calibrated model were made, with the following variations:

- 1) Hydraulic conductivity uniformly increased by a factor of 10;
- 2) Hydraulic conductivity uniformly decreased by a factor of 10;
- 3) Longitudinal dispersivity uniformly increased by a factor of 10;
- 4) Longitudinal dispersivity uniformly decreased by a factor of 10;
- 5) Anaerobic decay coefficient increased to 0.035 day^{-1} ;
- 6) Anaerobic decay coefficient decreased to 0.00035 day^{-1} ;
- 7) Retardation coefficient increased to 19.3; and
- 8) Retardation coefficient decreased to 1 (i.e., no retardation).

The results of the sensitivity analyses are shown graphically in Figures 5.4, 5.5, 5.6, and 5.7. These figures display the predicted BTEX distribution for 1995 versus distance along the centerline of the plume. This manner of displaying data is useful because the plume is narrow and migrates parallel to the model grid. Furthermore, the figures allow easy visualization of the changes in BTEX concentration caused by varying model input parameters.

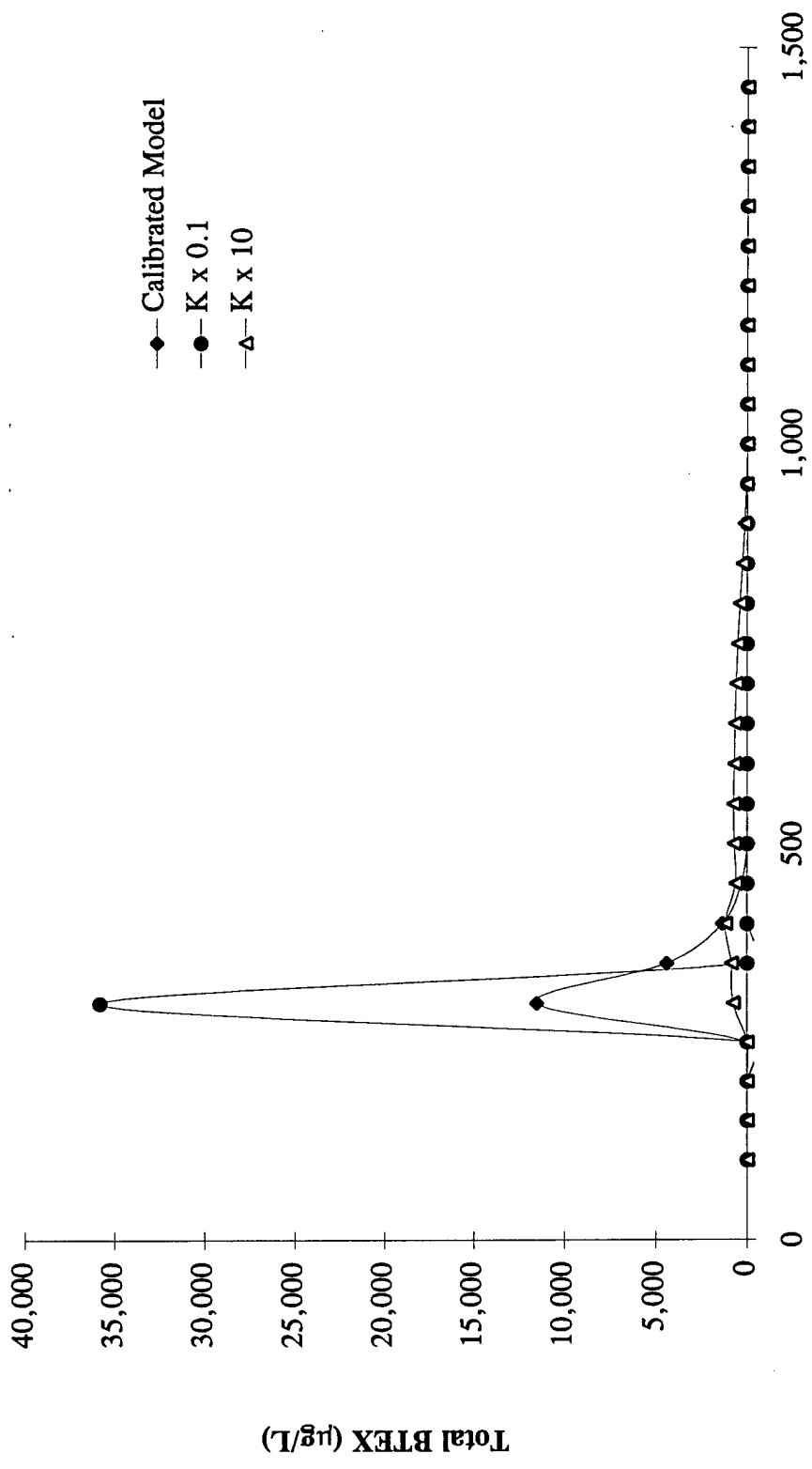


FIGURE 5.4

**PLOT OF TOTAL BTEX VERSUS
DISTANCE ALONG PLUME
CENTERLINE WITH VARYING
HYDRAULIC CONDUCTIVITY (K)**

Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC



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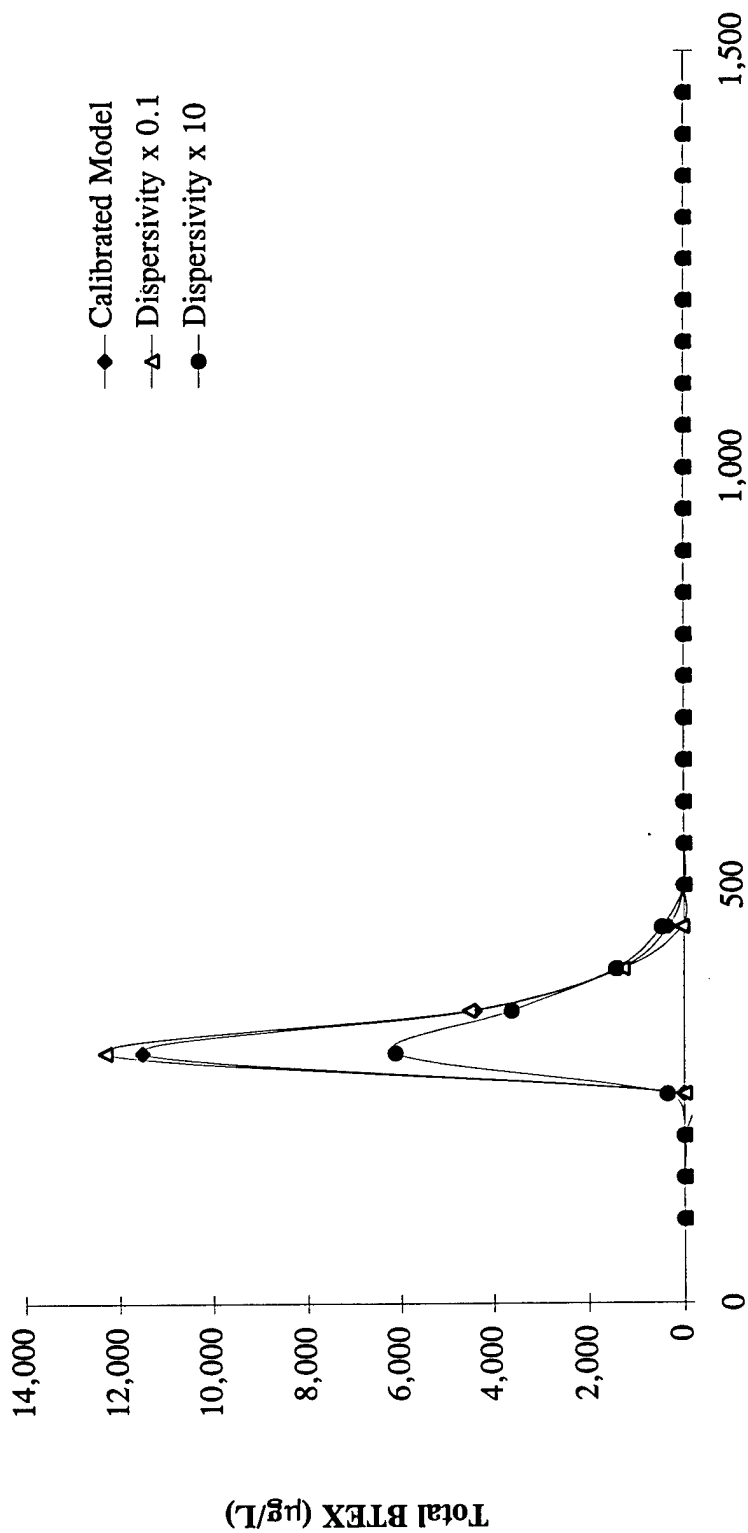


FIGURE 5.5

**PLOT OF TOTAL BTEX VERSUS
DISTANCE ALONG PLUME
CENTERLINE WITH VARYING
LONGITUDINAL DISPERSIVITY**

Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC



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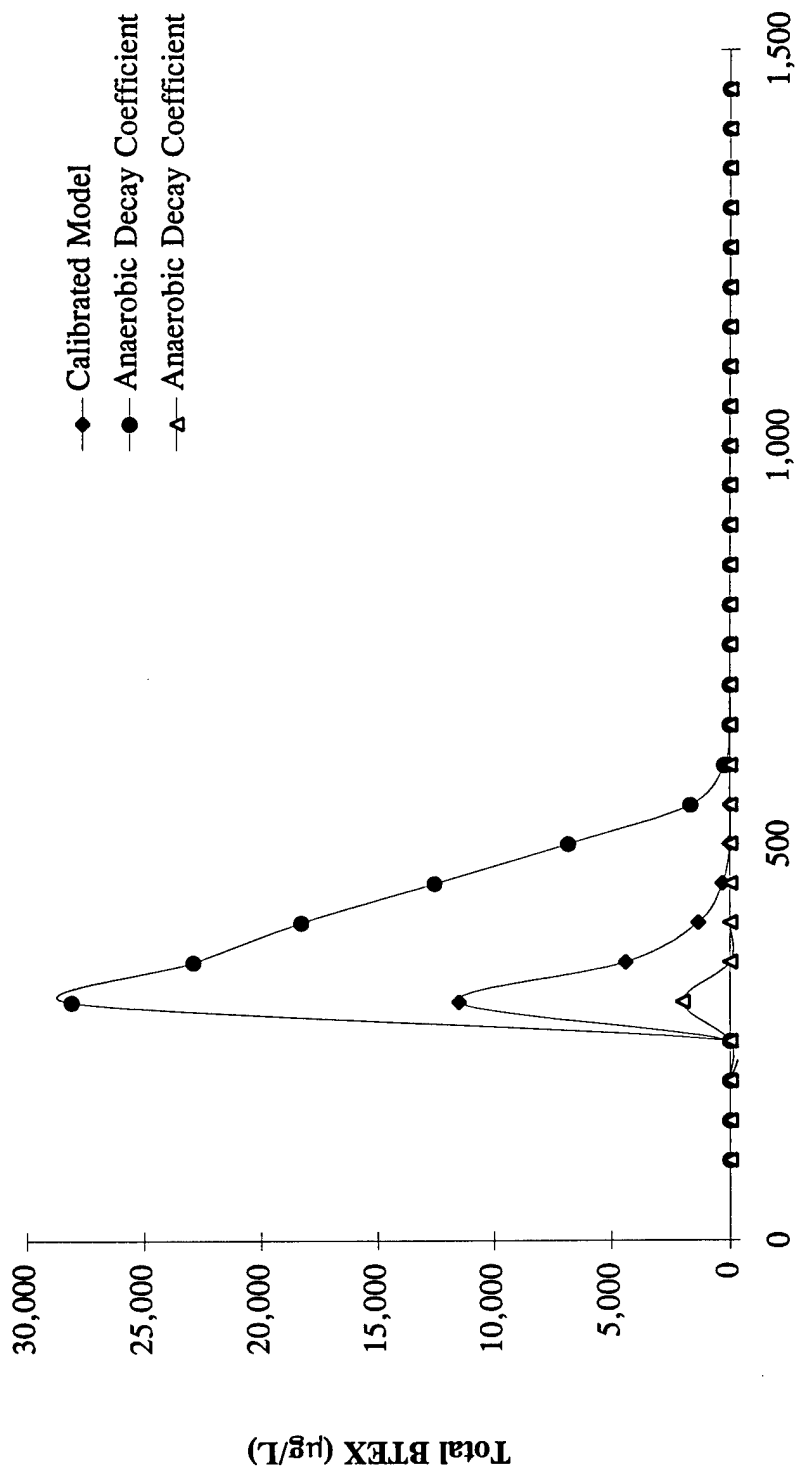


FIGURE 5.6

**PLOT OF TOTAL BTEX VERSUS
DISTANCE ALONG PLUME
CENTERLINE WITH VARYING
ANAEROBIC DECAY COEFFICIENT**

Intrinsic Remediation EE/CA
Former AGE Fueling Facility
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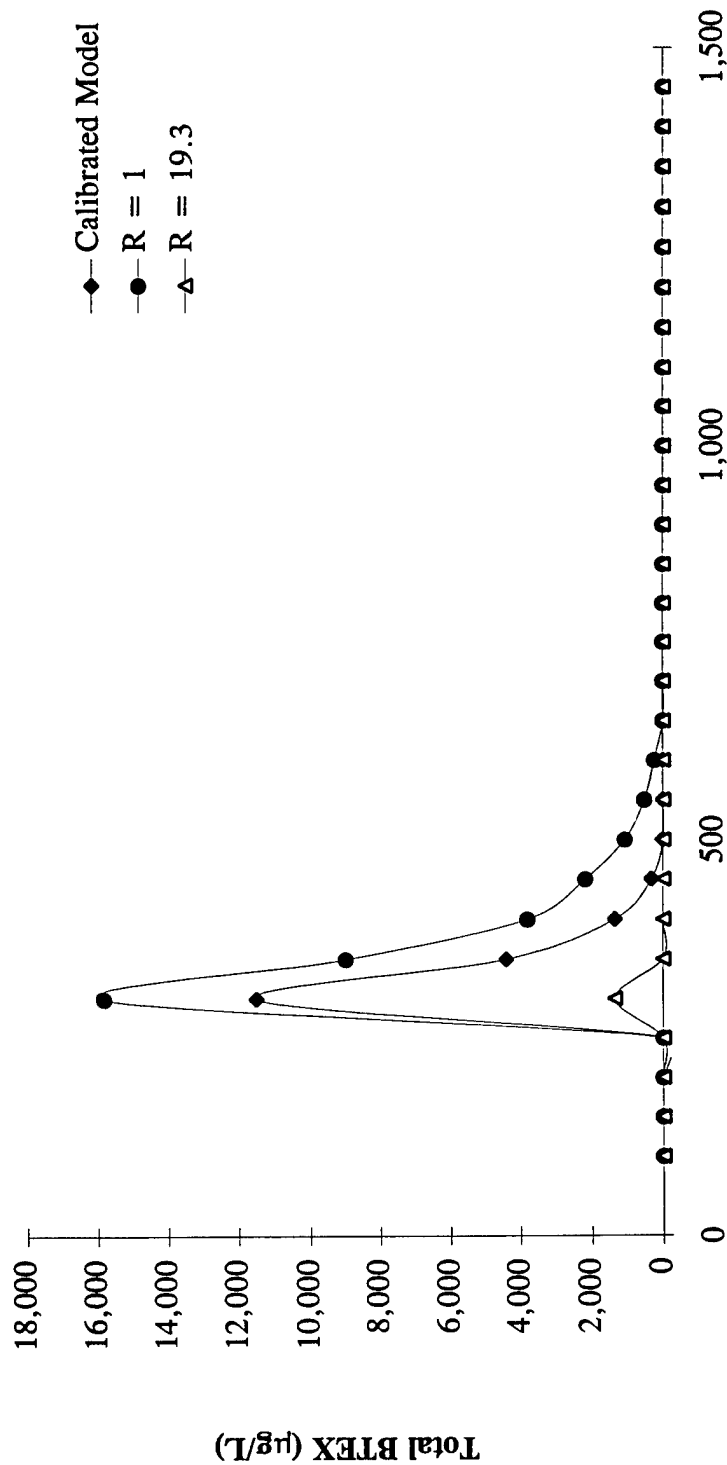


FIGURE 5.7

**PLOT OF TOTAL BTEX VERSUS
DISTANCE ALONG PLUME
CENTERLINE WITH VARYING
RETARDATION COEFFICIENT (R)**

Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC



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Uniformly increasing the hydraulic conductivity in the model by an order of magnitude (model K x 10) drastically increased the migration rate and biodegradation rate of the plume (Figure 5.4). In relation to the calibrated plume, the plume formed by the model with the higher hydraulic conductivity had a lower peak BTEX concentration (due to increased advective flow and biodegradation) and was spread much further downgradient (due to increased advective flow). Reduced peak concentrations were caused by an increased influx of electron acceptors in the highly conductive aquifer, increasing biodegradation of the plume in the source area. Also, the higher groundwater velocity more rapidly transported dissolved contaminant concentrations from the source area and produced greater downgradient spreading of the BTEX plume. In contrast, decreasing the hydraulic conductivity by an order of magnitude slowed plume migration, which in turn caused a large increase in modeled BTEX levels in the source area and a decreased downgradient plume extent. Increased BTEX concentrations in the source area are caused by a reduction in the mass of electron acceptors being brought into contact with the plume from upgradient locations as well as a reduction in the rate that dissolved BTEX mass is transported from the source area through advective flow.

Figure 5.5 illustrates the effects of varying longitudinal dispersivity. This model is relatively insensitive to dispersivity. Decreasing the dispersivity reduced the migration distance for the BTEX plume and slightly increased peak concentrations. Lowering dispersivity keeps the plume from spreading out into more electron-acceptor-rich portions of the aquifer. Conversely, increasing dispersivity produced lower BTEX concentrations in the source area while increasing the BTEX concentrations farther from the source area. Altering longitudinal dispersivity within the indicated range did not affect the overall length of the BTEX plume.

The effect of varying the anaerobic decay coefficient is shown in Figure 5.6. Increasing the anaerobic decay coefficient from 0.0035 day^{-1} to 0.035 day^{-1} significantly decreased BTEX concentrations and restricted plume migration. This result is not reflective of the actual site conditions. By reducing the anaerobic decay coefficient by an order of magnitude (to 0.00035 day^{-1}), the length of the modeled BTEX plume increased greatly, as did the maximum concentration. The predicted downgradient extent of the plume extended approximately 200 feet past its observed 1995 location.

Figure 5.7 shows the sensitivity of the model to the coefficient of retardation. The coefficient of retardation was decreased from the calibrated value of 1.93 to 1, which simulates no retardation. Retardation is used to describe the ratio of contaminant velocity to groundwater velocity; consequently retardation indirectly describes the exposure of dissolved contaminants to upgradient electron acceptors. Therefore, removing retardation from the model significantly increased the maximum BTEX concentrations and the downgradient extent of the plume. Conversely, increasing the coefficient of retardation to 19.3 significantly decreased the peak plume concentrations and limited the migration of the plume.

The results of the sensitivity analysis suggest that the calibrated model used for this report is reasonable. Increasing or decreasing the anaerobic decay coefficient, hydraulic conductivity, or the coefficient of retardation significantly affects the predicted BTEX concentration and distribution, resulting in modeled plumes that do not reflect

observations made at the site in 1995. The model is relatively insensitive to changes in longitudinal dispersivity.

5.6 MODEL RESULTS

To predict fate and transport of dissolved BTEX compounds at the AGE Fueling Facility, Bioplume II simulations were run assuming no contaminant source removal (model SETUP16), annual source removal over a 5-year period (model SR5), and annual source removal over a 3-year period (model SR3). The simulations were continued until the plume reached steady-state equilibrium (no source removal) or until the plume disappeared (source removal scenarios). As previously mentioned, continuing sources of groundwater contamination at the site exist in the form of soil contamination and mobile and residual LNAPL contamination. Contaminant source reduction in concert with natural attenuation can significantly reduce the longevity of the dissolved BTEX contamination at the site. The 3- and 5-year time periods for source removal were considered practical limits for currently available remedial technologies due to the present day LNAPL distribution, presence of clayey and silty strata below the site, and somewhat restricted site access due to the ongoing AGE operations and maintenance activities in surrounding areas.

Although the results of each model run varied depending on the amount of decrease in source injection concentration over time, two trends were consistently observed:

- 1) The plume shape in each simulation is initially elongated due to rapid advective transport of BTEX contamination and rapid biodegradation of BTEX at the plume periphery; and
- 2) The BTEX plume is predicted to completely dissipate within 4 years of complete source removal regardless of the scenario (SR3 or SR5).

The following sections describe the results of each Bioplume II model scenario. Comparisons to analytical models are provided in Appendix E. To simplify discussions regarding predicted cleanup time frames, model results that vary over time are referred to by both the number of simulation years (i.e., the number of years following calibration to observed data in 1995) and the calendar year. Likewise, plume migration distances were measured from a common location near the suspected point of release. This measurement point is in the vicinity of monitoring point MW-13 (see Figure 5.1).

5.6.1 No Source Removal (Model SETUP16)

Model SETUP16 simulated the migration and biodegradation of the BTEX plume assuming no source weathering or removal. This model assumed that the conditions that produced the calibrated model continue, including injection of BTEX compounds at the same rates. This extremely conservative (worst-case) simulation was run to predict BTEX distributions for 40 simulation years (i.e., model predictions until the year 2035). Contaminant migration during the simulation was relatively slow as a result of the moderate hydraulic conductivity and shallow hydraulic gradient at the site. Under this scenario, the BTEX plume achieves its maximum areal and downgradient extent in

approximately 10 simulation years (year 2005). Figure 5.8 presents the plume after 10 simulation years (year 2005) using Model SETUP16. This plume is approximately 200 feet longer than the original calibrated plume and has a maximum BTEX concentration of 12,565 $\mu\text{g/L}$, approximately 1,000 $\mu\text{g/L}$ higher than the calibrated maximum plume concentration of 11,506 $\mu\text{g/L}$. During years 10 through 40 (years 2005 through 2035), the areal extent of the dissolved BTEX plume does not expand further, and the maximum BTEX concentrations stabilize at a little over 12,000 $\mu\text{g/L}$.

Model SETUP16 is considered to be an extremely conservative, worst-case scenario because the model assumes that the BTEX source strength never decreases through time. As a result, the model predicts that with time the plume extent and maximum BTEX concentrations will stabilize and that they will never recede or decrease in concentration. It is more likely that as the source area continues to weather and degrade, the BTEX concentrations entering groundwater will diminish. Given a gradually decreasing source, the plume extent will gradually shrink back toward the source area and the maximum concentration in the source area will gradually decrease. The rate of plume recession will depend on the rate of source area weathering and degradation.

5.6.2 Twenty-Percent Annual Source Removal (Model SR5)

Model SR5 simulated the migration and biodegradation of the BTEX plume assuming a reduction in BTEX source concentrations over a 5-year period. Source removal is assumed to result from natural weathering and implementation of bioslurping and bioventing technologies. This time period was considered a practical implementation period for currently available remedial technologies based on the present day LNAPL distribution, presence of clayey and silty strata below the site, presence of a concrete cover over a portion of the site, and limited site access due to the ongoing AGE operations.

Model SR5 is identical to model SETUP16 with the exception of the annual source removal term. After the simulation of the plume to the present conditions, the concentration of hydrocarbons introduced into the system by the injection wells was reduced by 20 percent of the original amount each year for 5 years. The model simulation initiates source reduction during year 1996 and injection of BTEX is discontinued after year 2000.

The BTEX plume configurations resulting from model SR5 were similar to those predicted in model SETUP16 during the first five model years (1996 to 2000). After 7 years (year 2002), the downgradient extent of the plume reaches its maximum length, approximately 250 feet from the source area. Figure 5.9 shows the results of this model 2 years after completion of source removal (year 2002). Although the plume extent expanded during the first seven years, the maximum BTEX concentration in the source area decreased to less than 3,000 $\mu\text{g/L}$. In subsequent model years, both plume extent and concentrations decreased, with complete dissipation of the hydrocarbon plume occurring 4 years after completion of source removal (year 2004). This plume dissipation occurs because biodegradation rates due to replenished DO concentrations and anaerobic

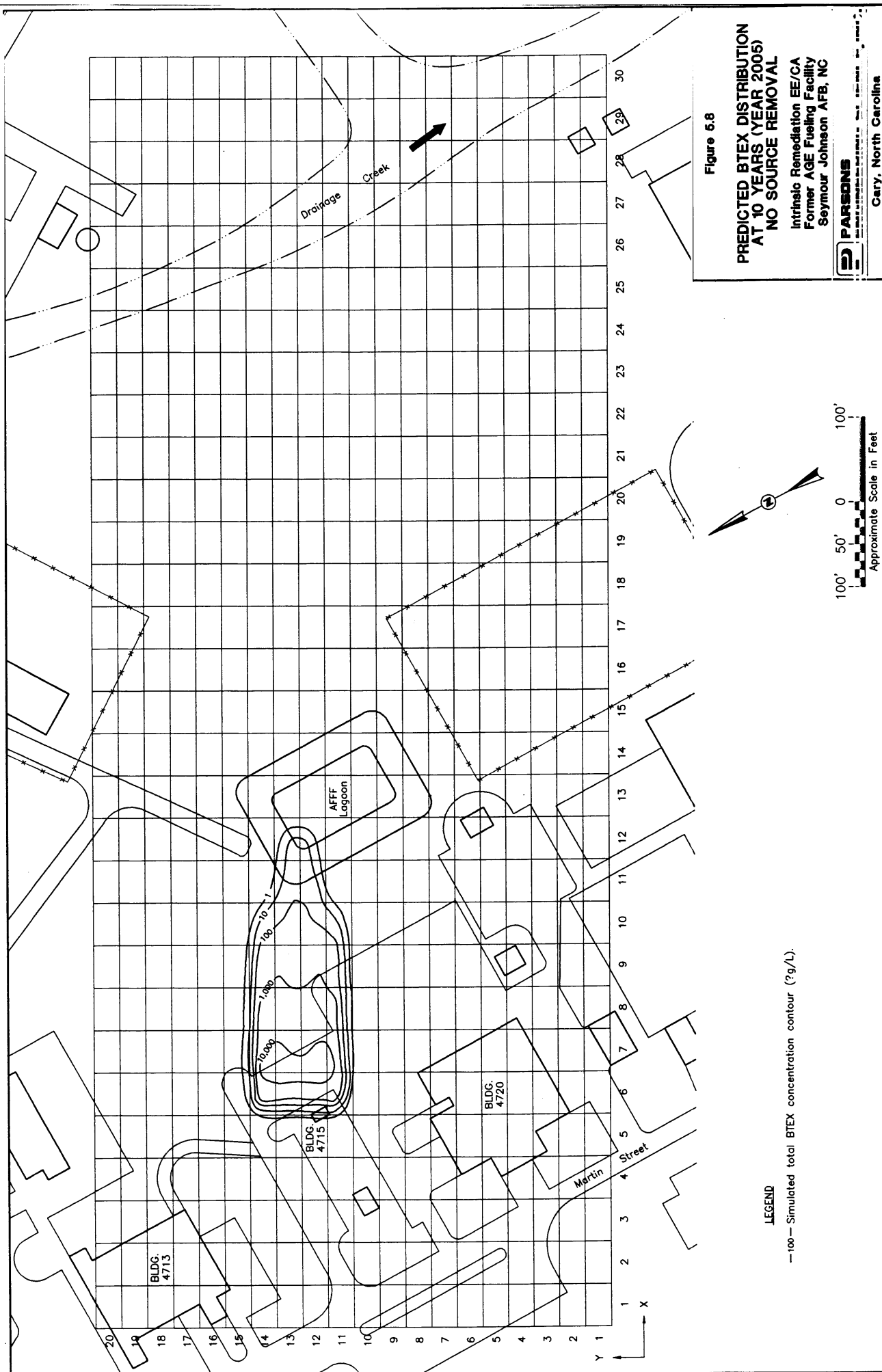
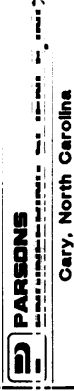


Figure 5.8

**PREDICTED BTEX DISTRIBUTION
AT 10 YEARS (YEAR 2005)
NO SOURCE REMOVAL**
Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC



Cary, North Carolina

5-26

LEGEND

—100— Simulated total BTEX concentration contour (?g/L).

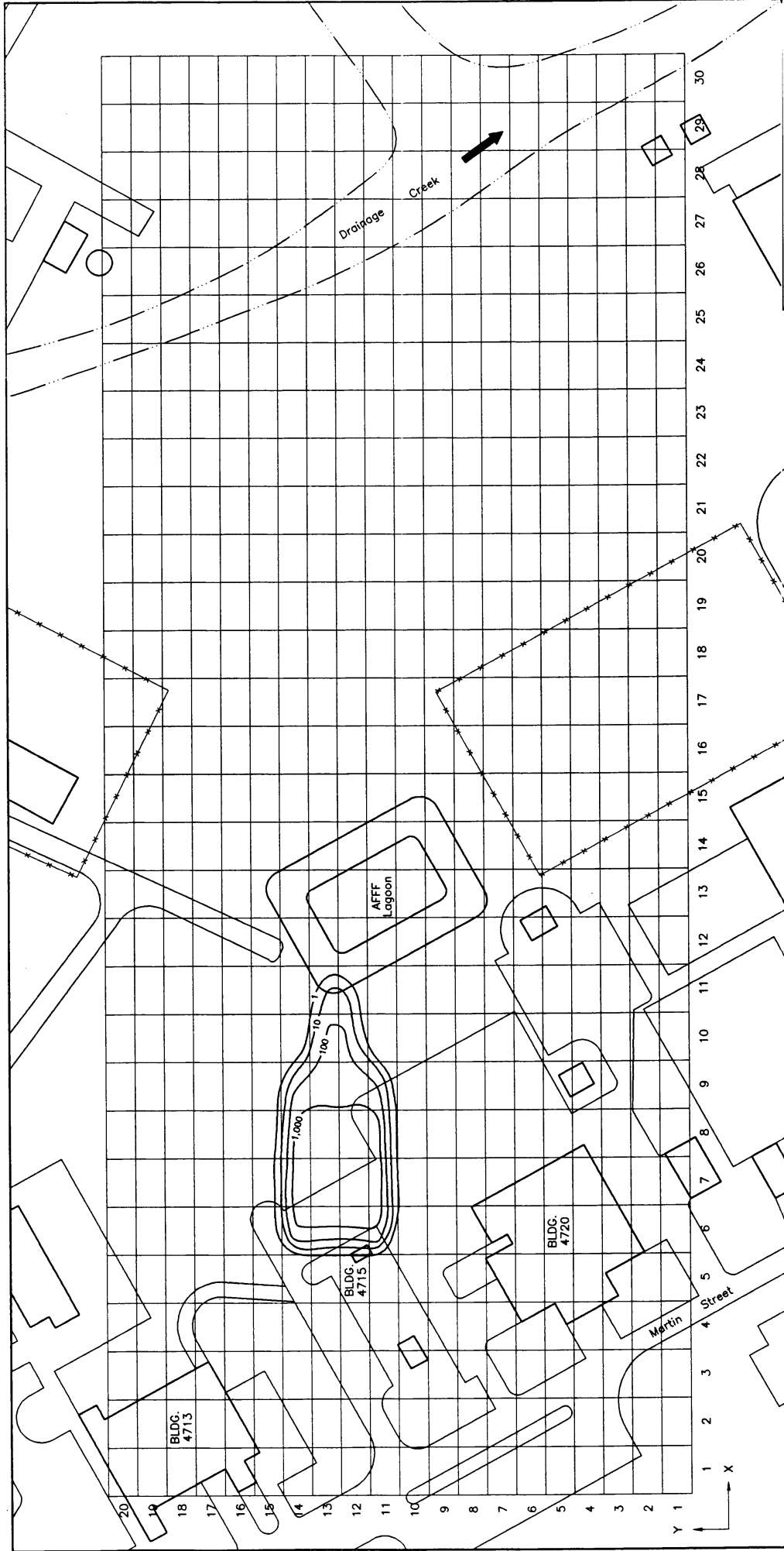


Figure 6.9
PREDICTED BTX CONCENTRATION DISTRIBUTION
AT 7 YEARS (YEAR 2002)
MODEL SR5 RESULTS
 Intrinsic Remediation EE/CA
 Former AGE Fueling Facility
 Seymour Johnson AFB, NC

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LEGEND
 —100— Simulated total BTX concentration contour (ug/L).

decay eventually exceed the rate at which dissolved BTEX concentrations are introduced into the aquifer.

5.6.3 Thirty-Three-Percent Annual Source Removal (Model SR3)

Model SR3 simulated the migration and biodegradation of the BTEX plume assuming a reduction in source BTEX concentrations over a 3-year period. These reductions are due to natural weathering, excavation of soil in the area of LNAPL contamination, and bioventing of perimeter soil contamination. Excavated soils would be treated in the Base landfarming operation, which operates under a state permit. The 3-year source removal time period was considered to approach the practical limits for currently available remedial technologies based on the present day LNAPL distribution, the presence of clayey and silty strata below the site, the presence of concrete cover over a portion of the site, and limited site access due to the ongoing AGE operations. This system is considered to remove the source from the site 2 years faster than the model SR5 scenario.

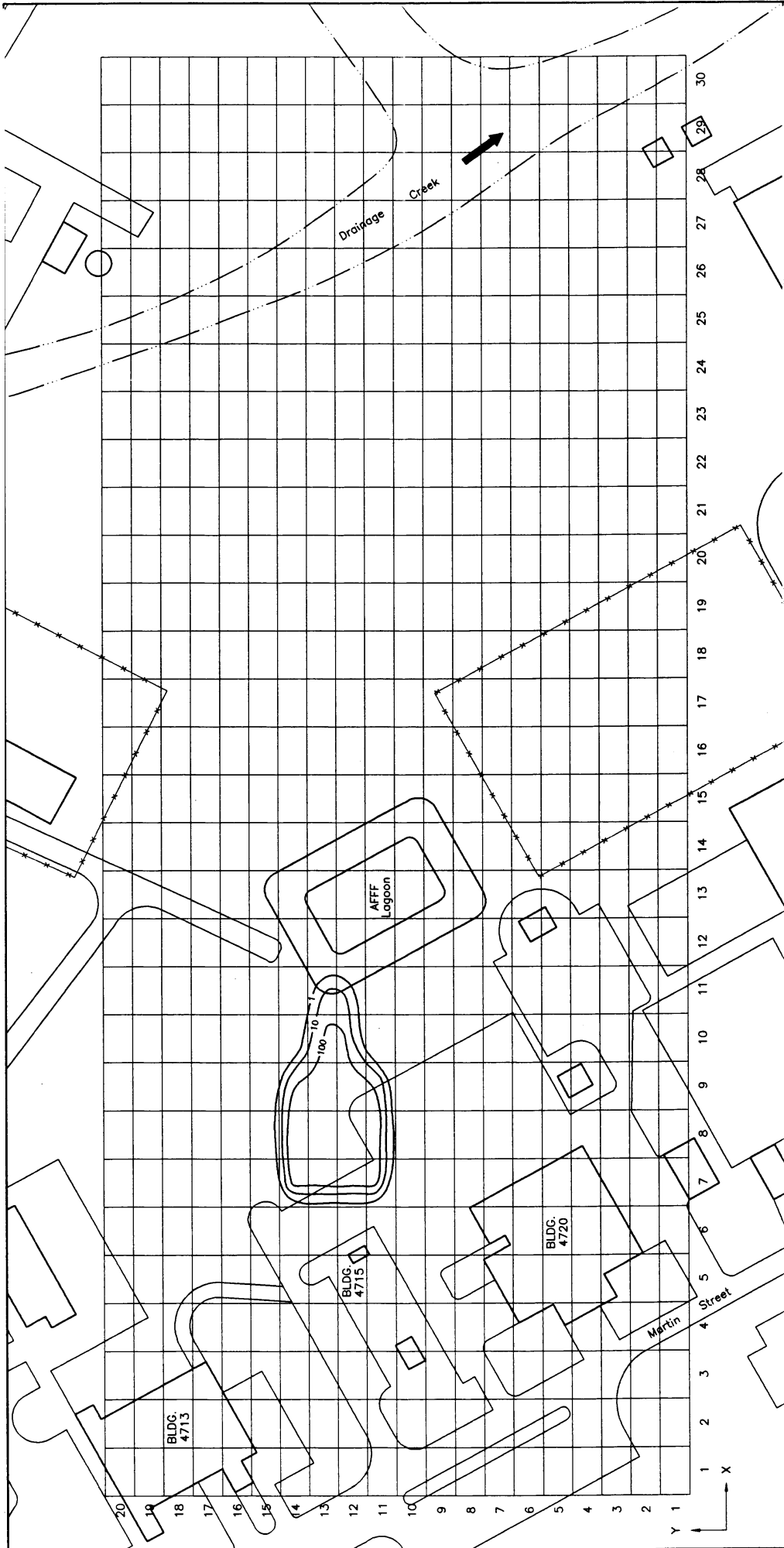
Model SR3 is identical to models SETUP16 and SR5 with the exception of the annual source removal term. After simulation of the plume to the present (1995) conditions, the concentration of BTEX introduced into the system by the injection wells was reduced by 33.3 percent of the original amount each year for 3 years. The model simulation initiates source reductions during year 1996 and assumes that the source reduction is complete after 3 years (e.g., by the year end in 1998).

The BTEX plume configurations resulting from model SR3 were nearly identical to those predicted in model SR5 during the model years from 1995 to 1998. Models SR3 and SR5 both suggest that the maximum downgradient extent of the BTEX plume will be approximately 250 feet from the source area; however, the maximum extent occurs in simulation year 5 (year 2000) for model SR3 rather than simulation year 7 (year 2002). Figure 5.10 shows the results of this model at 2 years after completion of source removal (year 2000). Although the plume extent expanded during the first five years, the maximum BTEX concentration in the source area had decreased to approximately 750 µg/L. In subsequent model years, both plume extent and concentration decreased, with complete dissipation of the hydrocarbon plume occurring 4 years after completion of source removal (year 2002). This plume dissipation occurs because biodegradation rate due to replenished DO concentrations and anaerobic decay eventually exceed the rate at which dissolved BTEX concentrations are introduced into the aquifer.

There are no appreciable differences in the BTEX distributions over time between the two source removal scenarios, SR3 and SR5. Both predict the maximum downgradient extent of dissolved BTEX will occur 2 years after complete source removal, and both predict complete dissipation of the plume 4 years after completion of source removal.

5.7 CONCLUSIONS

The results of three Bioplume II model scenarios for the former AGE fueling facility site suggest that the dissolved BTEX plume front is not likely to migrate more than 200 feet downgradient from its 1995 position. The first scenario, model SETUP16,



LEGEND
—100— Simulated total BTEX concentration contour (ug/L).

Figure 5.10

**PREDICTED BTEX DISTRIBUTION
AT 5 YEARS (YEAR 2000)
MODEL SR3 RESULTS**
Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC

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represents a worst-case situation in which conditions that produced the calibrated model were assumed to remain constant (i.e., source loading does not decrease with time). The second and third scenarios (models SR5 and SR3, respectively) assumed that source area remediation would reduce BTEX loading rates. SETUP16 results suggest that within 10 years (year 2005), the BTEX plume would reach its maximum extent, approximately 300 feet downgradient from the source area, before stabilizing. At that time, the maximum total BTEX concentration in the center of the plume would be 12,565 µg/L. The results of this model likely overestimate the extent of downgradient plume migration and the future dissolved BTEX concentrations.

Results of SR5 and SR3 suggest that after source reduction and removal, the BTEX plume will migrate no more than 250 feet from the source area. At the maximum plume extent, predicted BTEX concentrations range from 750 to 2,984 µg/L in the interior of the plumes. The results of both source removal scenarios suggest that within 4 years of completion of source removal, the BTEX plume will be completely degraded. Model simulations conducted during this project are conservative for several reasons, including the following:

- 1) Aerobic respiration, denitrification, iron reduction, sulfate reduction, and methanogenesis all are occurring at this site; however, DO was the only electron acceptor considered to react instantaneously (relative to the solute velocity) in model simulations. Anaerobic processes were simulated with a first-order decay constant.
- 2) The stoichiometry used to determine the ratio between electron acceptors and BTEX assumed that no microbial cell mass was produced during the reactions. As discussed in Section 4.3.2.1, this approach may be conservative.
- 3) The highest DO concentration observed at the site was 9.06 mg/L. The background DO concentration assumed during model simulations was 8.0 mg/L.

Models SETUP16, SR5, and SR3 represent endpoints in a continuum of probable scenarios at the former AGE fueling facility site. SETUP16 represents the "worst case" in that it assumes BTEX dissolution into the aquifer will continue indefinitely, while in reality BTEX loading rates will decrease as the mobile and residual product weathers and continuing dissolution removes more and more of those compounds. Model SR5 and SR3 are more optimistic predictions that assume source remediation will result in rapid decreases in BTEX dissolution. It is likely that future site conditions will fall somewhere between these endpoints, with the plume not migrating as far as indicated by SETUP16, but with BTEX in the source area persisting longer than predicted by SR5 and SR3.

SECTION 6

COMPARATIVE ANALYSIS OF REMEDIAL ALTERNATIVES

This section presents the development and comparative analysis of three groundwater remedial alternatives for the former AGE fueling facility site at Seymour Johnson AFB. The intent of this evaluation is to determine if intrinsic remediation is an appropriate and cost-effective remedial approach to consider when developing final remedial strategies for the site, especially when combined with other conventional remedial technologies.

Section 6.1 presents the evaluation criteria used to evaluate groundwater remedial alternatives. Section 6.2 discusses the development of remedial alternatives considered as part of this demonstration project. Section 6.3 provides a brief description of each of these remedial alternatives. Section 6.4 provides a more detailed analysis of the remedial alternatives using the defined remedial alternative evaluation criteria. The results of this evaluation process are summarized in Section 6.5.

6.1 REMEDIAL ALTERNATIVE EVALUATION CRITERIA

The evaluation criteria used to identify appropriate remedial alternatives were adapted from those recommended by the USEPA (1988) for selecting remedies for Superfund sites (Office of Solid Waste and Emergency Response [OSWER] Directive 9355.3-01). These criteria include (1) long-term effectiveness and permanence, (2) technical and administrative implementability, and (3) relative cost. The following sections briefly describe the scope and purpose of each evaluation criterion. This EE/CA focuses on the potential use of intrinsic remediation and source reduction technologies to reduce BTEX concentrations within the shallow groundwater to levels that do not exceed regulatory action levels.

6.1.1 Long-Term Effectiveness and Permanence

Each remedial technology or remedial alternative (which can be a combination of remedial approaches and technologies such as intrinsic remediation and institutional controls) was analyzed to determine how effectively it will minimize groundwater contaminant plume expansion so that groundwater quality standards can be achieved at a downgradient POC. The expected technical effectiveness was evaluated based on case histories from other sites with similar conditions. The ability to minimize potential impacts to surrounding facilities and operations was considered. Also, the ability of each remedial alternative to protect both current and potential future receptors from potential risks associated with potential exposure pathways was qualitatively assessed. These evaluation criteria also include permanence and the ability to reduce contaminant mass, toxicity, and volume. Time to implementation and time until protection is achieved are discussed. Long-term reliability for providing continued protection, including an assessment of potential for failure of the technology and the potential threats resulting from such a failure, also was evaluated.

6.1.2 Implementability

The technical implementation of each remedial technology or remedial alternative was evaluated in terms of technical feasibility and availability. Potential shortcomings and difficulties in construction, operations, maintenance, and monitoring are presented and weighed against perceived benefits. Requirements for any post-implementation site controls, such as LTM and land use restrictions, are described. Details on administrative feasibility in terms of the likelihood of public acceptance and the ability to obtain necessary approvals are discussed.

6.1.3 Cost

The total cost (present worth) of each remedial alternative was estimated for relative comparison following USEPA (1988) guidance. An estimate of capital costs, and operations and post-implementation costs for site monitoring and controls is included. An annual adjustment factor of 7 percent was assumed in present worth calculations. The annual adjustment factor is the difference between the rate of inflation and the cost of money (USEPA, 1988).

6.2 FACTORS INFLUENCING ALTERNATIVES DEVELOPMENT

Several factors were considered during the identification and screening of remedial technologies for addressing shallow groundwater contamination at the former AGE fueling facility site at Seymour Johnson AFB. Factors considered included the objectives of the natural attenuation demonstration program; contaminant, groundwater, and soil properties; current and future land uses; and potential receptors and exposure pathways. The following sections briefly describe each of these factors and how they were used to narrow the list of potentially applicable remedial technologies to the final remedial alternatives considered for the site.

6.2.1 Program Objectives

The intent of the intrinsic remediation demonstration program sponsored by AFCEE is to develop a systematic process for scientifically investigating and documenting naturally occurring subsurface attenuation processes that can be factored into overall site remediation plans. The objectives of this program and the specific study at the former AGE fueling facility site are to provide solid evidence of intrinsic remediation of dissolved fuel hydrocarbons so that this information can be used to develop an effective groundwater remediation strategy. A secondary goal of this multi-site initiative is to provide a series of regional case studies that demonstrate that natural processes of contaminant degradation can often reduce contaminant concentrations in groundwater to below acceptable cleanup standards before completion of potential exposure pathways.

Because the objective of this program is to study natural processes in the saturated zone rather than all contaminated media (e.g., soil, soil gas, etc.), technologies have been evaluated based on their potential impact on shallow groundwater and phreatic soils. Technologies that can reduce vadose zone contamination and partitioning of contaminants into groundwater also have been evaluated. Many of the source removal

technologies evaluated in this section also will reduce soil and soil gas contamination, but it is important to emphasize that the remedial alternatives developed in this document are not intended to remediate all contaminated site media. However, remediation of contamination in the vadose zone can reduce contaminant leaching, further increasing the effectiveness of natural attenuation mechanisms in groundwater.

Additional program objectives set forth by AFCEE include cost effectiveness and minimization of remediation waste. Technologies that may meet these criteria include institutional controls, SVE, bioventing, biosparging, bioslurping, groundwater pump and treat, and intrinsic remediation. Soil excavation, slurry walls, sheet piling, carbon adsorption, ex situ biological or chemical treatment, and onsite/offsite disposal are generally not considered attractive technologies under this program.

6.2.2 Contaminant Properties

The site-related contaminants considered as part of this demonstration at the former AGE fueling facility site are the BTEX compounds. The source of this contamination is a combination of weathered diesel fuel, gasoline, and JP-4 present as mobile and residual LNAPL in the vadose zone, capillary fringe, and saturated soil on the site. The physiochemical characteristics of the fuels and the individual BTEX compounds will greatly influence the effectiveness and selection of a remedial technology.

Petroleum hydrocarbon mixtures, such as the fuels formerly stored at the site, consist of more than 300 compounds with different physiochemical characteristics. JP-4 is manufactured by blending various petroleum distillate products such as naphtha, gasoline, and kerosene (Biomedical and Environmental Information Analysis [BEIA], 1989). The reported major compound categories of JP-4, in decreasing order of prominence, are paraffins, monocycloparaffins, dicycloparaffins, alkylbenzenes, indans, tetralins, and naphthalenes (BEIA, 1989). JP-4 is classified as an LNAPL with a liquid density of approximately 0.75 gram per cubic centimeter (g/cc) at 20°C (BEIA, 1989). Because JP-4 is less dense than water, the LNAPL may become concentrated in the capillary fringe. Some of the individual JP-4 constituents sorb very well to the soil matrix, others dissolve quickly into percolating groundwater, and yet others may volatilize into soil vapor. This "weathering" process results in a variable distribution of individual JP-4 components in the soil, soil atmosphere, and groundwater with time and distance from the release (BEIA, 1989). Constituents in JP-4 range from slightly to highly soluble in water, with an overall solubility of approximately 300 mg/L (BEIA, 1989). JP-4 also can act as a primary substrate for biological metabolism. Simultaneous biodegradation of aliphatic, aromatic, and alicyclic hydrocarbons has been observed. In fact, mineralization rates of hydrocarbons in mixtures, such as JP-4, may be faster than mineralization of the individual constituents as a result of cometabolic pathways (Jamison *et al.*, 1975; Perry, 1984).

Diesel fuel is largely a mixture of C10 through C19 hydrocarbons, usually the fraction that distills after kerosene in the 200°C to 400°C range (BEIA, 1989). The composition of diesel fuel has been quantified as approximately 64 percent aliphatic hydrocarbons, 1 to 2 percent olefinic hydrocarbons, and 35 percent aromatic hydrocarbons, including alkylbenzenes and 2-3 ring aromatics (BEIA, 1989). The behavior of diesel fuel in the

subsurface environment is similar to that of JP-4. Biodegradation of the petroleum hydrocarbons in diesel fuel may occur under conditions favorable for microbial activity and when these hydrocarbons are freely available to the microorganisms (BEIA, 1989).

Gasoline is classified as an LNAPL with a liquid density of approximately 0.73 g/cc at 20°C (BEIA, 1989). Because gasoline is less dense than water, the LNAPL may become concentrated in the capillary fringe. Some of the individual gasoline constituents can either sorb to the soil matrix, dissolve into groundwater, or volatilize into soil vapor. Constituents in gasoline range from slightly to highly soluble in water. Overall solubility is approximately 300 mg/L. Gasoline is also a primary substrate for biological metabolism.

The BTEX compounds are generally volatile, highly soluble in water, and adsorb less strongly to soil than other hydrocarbons in the petroleum mixture. These characteristics allow the BTEX compounds to leach more rapidly from contaminated soil into groundwater and to migrate as dissolved contamination (Lyman *et al.*, 1992). All of the BTEX compounds are highly amenable to in situ degradation by both biotic and abiotic mechanisms.

Benzene is very volatile with a vapor pressure of 76 millimeters of mercury (mm Hg) at 20°C and a Henry's Law Constant of approximately 0.0054 atmosphere-cubic meters per mole (atm-m³/mol) at 25°C (Hine and Mookerjee, 1975; Jury *et al.*, 1984). The solubility of pure benzene in water at 20°C has been reported to be 1,780 mg/L (Verschueren, 1983). Benzene is normally biodegraded to carbon dioxide, with catechol as a short-lived intermediate (Hopper, 1978; Ribbons and Eaton, 1992).

Toluene is also volatile, with a vapor pressure of 22 mm Hg at 20°C and a Henry's Law Constant of about 0.0067 atm-m³/mol at 25°C (Pankow and Rosen, 1988; Hine and Mookerjee, 1975). Toluene sorbs more readily to soil media relative to benzene, but still is very mobile. The solubility of pure toluene in water at 20°C is approximately 515 mg/L at 20°C (Verschueren, 1983). Toluene has been shown to degrade to pyruvate, caetaldehyde, and completely to carbon dioxide via the intermediate catechol (Hopper, 1978; Wilson *et al.*, 1986; Ribbons and Eaton, 1992).

Ethylbenzene has a vapor pressure of 7 mm Hg at 20°C and a Henry's Law Constant of 0.0066 atm-m³/mol (Pankow and Rosen, 1988; Valsaraj, 1988). Ethylbenzene sorbs more strongly to soils than benzene but less strongly than toluene (Abdul *et al.*, 1987). Pure ethylbenzene is also less soluble than benzene and toluene in water at 152 mg/L at 20°C (Verschueren, 1983; Miller *et al.*, 1985). Ethylbenzene ultimately degrades to carbon dioxide via its intermediate 3-ethylcatechol (Hopper, 1978; Ribbons and Eaton, 1992).

The three isomers of xylene have vapor pressures ranging from 7 to 9 mm Hg at 20°C and Henry's Law Constants of between 0.005 and 0.007 atm-m³/mol at 25°C (Mackay and Wolkoff, 1973; Hine and Mookerjee, 1975; Pankow and Rosen, 1988). Of all of the BTEX compounds, xylenes sorb most strongly to soil, but still can leach from soil into the groundwater (Abdul *et al.*, 1987). Pure xylenes have water solubilities of 152 to 160 mg/L at 20°C (Bohon and Claussen, 1951; Mackay and Shiu, 1981; Isnard and

Lambert, 1988). Xylenes can degrade to carbon dioxide via pyruvate carbonyl intermediates (Hopper, 1978; Ribbons and Eaton, 1992).

On the basis of these physiochemical characteristics, intrinsic remediation, SVE, bioventing, bioslurping, biosparging, and groundwater extraction/air stripping technologies could all be effective at collecting, destroying, and/or treating BTEX contaminants at the former AGE fueling facility site.

6.2.3 Site-Specific Conditions

Three general categories of site-specific characteristics were considered when identifying remedial technologies for comparative evaluation as part of this demonstration project. The first category was physical characteristics such as groundwater depth, gradient, flow direction, and soil type. The second category was the site geochemistry, or how the site contaminants are interacting with electron acceptors, microorganisms, and other site contaminants. Both of these categories influences the types of remedial technologies most appropriate for the site. The third category involved assumptions about future land use and potential receptors and exposure pathways. Each of these site-specific characteristics have influenced the selection of remedial alternatives included in the comparative evaluation.

6.2.3.1 Physical Characteristics

Site geology and hydrogeology will have a profound effect on the transport of contaminants and the effectiveness and scope of required remedial technologies at a given site. Hydraulic conductivity is perhaps the most important aquifer parameter governing groundwater flow and contaminant transport in the subsurface. The velocity of the groundwater and dissolved contamination is directly related to the hydraulic conductivity of the saturated zone. Investigations performed previously at Seymour Johnson AFB indicated a range of hydraulic conductivity of the shallow aquifer from 2.5 to 42.5 ft/day, with an average value of about 15 ft/day. Groundwater model calibration indicated that a K of 7.5 ft/day best matched observed contaminant plume formation at the former AGE fueling facility site. The average hydraulic conductivity in combination with the relatively flat average hydraulic gradient of 0.005 ft/ft observed at this site yields a groundwater flow velocity of 50 to 100 ft/year. This velocity, in conjunction with the flow variations induced by differential recharge, directly influences the fate and transport of contaminants by limiting the rate of contamination migration. As a result, the shallow groundwater contaminant plume has migrated relatively slowly at the site.

Although a moderate to high hydraulic conductivity can result in considerable plume expansion and migration, this same characteristic also will enhance the effectiveness of remedial technologies, such as groundwater extraction, biosparging, and intrinsic remediation. For example, it should be less expensive and time-consuming to capture and treat the contaminant plume using a network of extraction wells in areas of moderate to high hydraulic conductivity. The effectiveness of biosparging may also be increased in sandy aquifers because of reduced entry pressures and increased radius of influence. Greater hydraulic conductivity also increases the amount of contaminant mass traveling through the biosparging network. Contaminant recovery also may be maximized when

contaminants are not significantly sorbed to and retarded by phreatic soil. The relatively low TOC content of uncontaminated aquifer materials at Seymour Johnson AFB (0.06 to 0.48 percent) will tend to minimize sorption and allow mobility of BTEX compounds.

6.2.3.2 Geochemical Characteristics

To satisfy the requirements of indigenous microbial activity and intrinsic remediation, the aquifer also must provide an adequate and available carbon or energy source, electron acceptors, essential nutrients, and proper ranges of pH, temperature, and redox potential. Data collected as part of the field work phase of this demonstration project and described in Sections 3 and 4 of this document indicate that the former AGE fueling facility site is characterized by adequate and available hydrocarbon/energy sources and electron acceptors that support measurable biodegradation of petroleum fuel contamination by indigenous microorganisms. DO, sulfate, ferrous iron, and carbon dioxide (which is utilized during methanogenesis) represent significant sources of electron acceptor capacity for the biodegradation of BTEX compounds at the site. Further, because fuel-hydrocarbon-degrading microorganisms have been known to thrive under a wide range of temperature and pH conditions (Freeze and Cherry, 1979), the physical and chemical conditions of the groundwater and phreatic soil at the site are not likely to inhibit microorganism growth.

Fuel-hydrocarbon-degrading microorganisms are ubiquitous, and as many as 28 hydrocarbon-degrading isolates (bacteria and fungi) have been discovered in different soil environments (Davies and Westlake, 1979; Jones and Eddington, 1968). Indigenous microorganisms have a distinct advantage over microorganisms injected into the subsurface to enhance biodegradation because indigenous microorganisms are well adapted to the physical and chemical conditions of the subsurface in which they reside (Goldstein *et al.*, 1985). Microbe addition was not considered a viable remedial technology for the former AGE fueling facility site.

6.2.3.3 Potential Exposure Pathways

A pathways analysis identifies the potential human and ecological receptors that could come into contact with site-related contamination, and the pathways through which these receptors might be exposed. To have a complete exposure pathway, there must be a source of contamination, a mechanism(s) of release, a pathway of transport to an exposure point, an exposure point, and a receptor. If any of these elements do not exist, the exposure pathway is considered incomplete, and receptors will not come into contact with site-related contamination. Evaluation of the potential long-term effectiveness of any remedial technology or remedial alternative as part of this demonstration project includes determining the potential for pathway completion. If a completed exposure pathway exists, potential long-term remedial options may still be sufficient to maintain exposure concentrations below regulatory levels. However, establishing site-specific risk-based cleanup levels is beyond the scope of this demonstration.

Assumptions about current and future land use at a site form the basis for identifying potential receptors, potential exposure pathways, reasonable exposure scenarios, and appropriate remediation goals. USEPA (1991) advises that the land use associated with

the highest (most conservative) potential level of exposure and risk that can reasonably be expected to occur should be used to guide the identification of potential exposure pathways and to determine the level to which the site must be remediated. The source area consists of mobile and residual LNAPL in the subsurface beneath the former AGE fueling facility site. The groundwater contaminant plume originating from the site is migrating primarily to the southeast and has impacted shallow groundwater in an irregularly shaped area within 200 feet of the source area (Figure 4.3). Concrete and asphalt parking areas and undeveloped vegetated areas overlie the contaminant plume. Warehouses, roadways, maintenance buildings, and office buildings are located on adjacent properties. The current and anticipated future land use within the contaminant plume is entirely industrial (i.e., Air Force operations).

Although it is not within the scope of this demonstration, a risk assessment may be required to evaluate potential risks. Under reasonable current land use assumptions, potential receptors include only worker (Air Force personnel and contractor) populations. It is unlikely that workers could be exposed to site-related contamination in phreatic soils or shallow groundwater unless this material is removed during future construction excavations or remedial activities. Because groundwater is located at a depth of approximately 10 to 12 feet bls, it is possible that utility workers could be exposed to shallow groundwater contamination. Shallow groundwater is not currently used to meet any water supply demands at Seymour Johnson AFB. All on-Base water supply demands are met by the City of Goldsboro. Exposure pathways involving other environmental media such as shallow soils and soil gas in the source area were not considered as part of this project, but should be considered in overall site remediation decisions. In the event future construction activities are planned for the former AGE fueling facility site, special precautions should be taken to ensure environmental safety and limit worker exposure.

Migration of contaminated shallow groundwater resulting in a discharge into the downgradient drainage creek could complete an exposure pathway to human or ecological receptors via dermal contact or possible ingestion. However, it is very unlikely that detectable hydrocarbon concentrations could reach the creek. The drainage creek is located approximately 850 feet downgradient from the leading edge of the contaminant plume. A conservative (biologically recalcitrant) tracer traveling at the groundwater velocity would require approximately 8.5 to 17 years to reach the creek. However, fate and transport modeling suggests that the contaminant plume will not travel this distance due to natural attenuation. The most conservative model (SETUP16) predicts that the leading edge will not advance more than 100 feet before stabilizing. In the unlikely event that contaminants reach the drainage creek, BTEX concentrations almost certainly would be diluted instantly to below analytical detection limits.

Assumptions about hypothetical future land uses also must be made to ensure that the remedial technology or alternative considered for shallow groundwater at the site is adequate and sufficient to provide long-term protection. No changes in land use are anticipated in the foreseeable future, so the assumption of continued industrial (Air Force operations) land use at the Base is appropriate. As a result, potential future receptors include only worker (Air Force personnel and contractor) populations on the Base. The potential future exposure pathways involving workers are identical to those under current

conditions provided shallow groundwater is not used to meet industrial water demands. In summary, the use of intrinsic remediation at this site will require that the source area be maintained as industrial property and that restrictions on groundwater use be enforced in the area from the former AGE fueling facility site downgradient to the drainage creek.

6.2.3.4 Remediation Goals for Shallow Groundwater

Model results suggest that BTEX compounds are not likely to move more than 300 feet downgradient from the source area, assuming contaminants are introduced into the aquifer at a constant rate. Without source reduction, the contaminant plume should reach steady-state conditions within 50 years. If active source area remediation were implemented (e.g., bioslurping and bioventing), and as residual LNAPL weathers, BTEX loading rates will decrease, and the extent of BTEX migration will likely be much more limited. Therefore, locations between the source area and the downgradient drainage creek have been identified as the POCs for groundwater remedial activities because the creek appears to be beyond the maximum extent of future contaminant migration. These are suitable locations for monitoring and for demonstrating compliance with protective groundwater quality standards (i.e., promulgated federal MCLs and North Carolina groundwater quality standards).

This remedial strategy assumes that compliance with promulgated, single-point remediation goals is not necessary if site-related contamination does not pose a threat to human health or the environment (i.e., exposure pathways are incomplete). Thus, the magnitude of required remediation in areas that can and will be placed under institutional control is different from the remediation that is required in areas that may be available for unrestricted use. The primary RAO for shallow groundwater within and downgradient of the former AGE fueling facility site is limiting plume expansion to prevent exposure of downgradient receptors to concentrations of BTEX in groundwater at levels that could pose a risk. This means that viable remedial alternatives must be able to achieve concentrations that minimize plume migration and/or expansion. The RAO for shallow groundwater at the POC is attainment of North Carolina groundwater standards for each of the BTEX compounds listed in Table 6.1. Although it is unlikely that site groundwater would be ingested by humans, this level of long-term protection is appropriate, because the shallow groundwater in this area is classified by North Carolina as a potential potable water source.

In summary, available data suggest that there is currently no completed potential exposure pathway at the former AGE fueling facility site. Moreover, it is unlikely that potential exposure pathways involving shallow groundwater would be completed under future land use assumptions, provided use of groundwater as a potable or industrial source of water is prohibited by institutional controls within the source area and between the source area and the downgradient drainage creek. Thus, institutional controls are likely to be a necessary component of any groundwater remediation strategy for this site. The required duration of these institutional controls may vary depending on the effectiveness of the selected remedial technology at reducing contaminant mass and concentration in the groundwater at the source area.

TABLE 6.1
POINT-OF-COMPLIANCE REMEDIATION GOALS
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY SITE
SEYMOUR JOHNSON AFB, NORTH CAROLINA

Compound	North Carolina Groundwater Quality Standards ($\mu\text{g/L}$)
Benzene	1
Toluene	1,000
Ethylbenzene	29
Total Xylenes	530

Source: North Carolina Administrative Code, Title 15A, Subchapter 2L.

6.2.4 Summary of Remedial Technology Screening

Several remedial technologies have been identified and screened for use in managing the shallow groundwater contamination at the former AGE fueling facility site. Table 6.2 identifies the initial remedial technologies considered as part of this demonstration and those retained for detailed comparative analysis. Screening was conducted systematically by considering the program objectives of the AFCEE intrinsic remediation demonstration, physiochemical properties of the BTEX compounds, and other site-specific characteristics such as hydrogeology, land use assumptions, potential exposure pathways, and appropriate remediation goals. All of these factors will influence the technical effectiveness, implementation, and relative cost of technologies for remediating shallow groundwater underlying and migrating from the site. The remedial technologies retained for development of remedial alternatives and comparative analysis include institutional controls, intrinsic remediation, LTM, bioslurping, bioventing, biosparging, SVE, and mobile-LNAPL skimming.

6.3 BRIEF DESCRIPTION OF REMEDIAL ALTERNATIVES

This section describes how remedial technologies retained from the screening process were combined into three remedial alternatives for the former AGE fueling facility site. Comparative analyses of effectiveness, implementability, and cost are presented in Section 6.4.

6.3.1 Alternative 1 - Intrinsic Remediation, Mobile LNAPL Recovery, and Institutional Controls with Long-Term Groundwater Monitoring

Alternative 1 includes four components: intrinsic remediation, mobile LNAPL recovery, institutional controls, and long-term groundwater monitoring. Intrinsic remediation is proposed to remediate fuel hydrocarbon contaminants dissolved in the groundwater. Mobile LNAPL recovery is proposed to reduce the source, thereby decreasing the expected time frame for remediation. Institutional controls are proposed to ensure that potential receptor pathways are not completed during site remediation. Finally, long-term groundwater monitoring is proposed to demonstrate compliance with remediation objectives.

Intrinsic remediation is achieved when natural attenuation mechanisms bring about a reduction in the total mass of a contaminant in the soil or dissolved in groundwater. Intrinsic remediation results from the integration of several subsurface attenuation mechanisms that are classified as either destructive or nondestructive. Destructive attenuation mechanisms include biodegradation, abiotic oxidation, and hydrolysis. Nondestructive attenuation mechanisms include sorption, dilution (caused by dispersion and infiltration), and volatilization. In some cases, intrinsic remediation will reduce dissolved contaminant concentrations below numerical concentration goals intended to be protective of human health and the environment. As indicated by the evidence of intrinsic remediation described in Section 4, these processes are occurring at the former AGE fueling facility site and will continue to reduce contaminant mass in the plume area.

TABLE 6.2
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY SITE
SEYMOUR JOHNSON AFB, NORTH CAROLINA

General Response Action	Technology Type	Process Option	Implementability	Retain
Long-Term Monitoring	Periodic Groundwater Monitoring	Confirmation Wells	Many existing wells are available to confirm the progress of remediation.	Yes
		Point-of-Compliance Wells	Sufficient distance exists between the plume and point-of-compliance to locate several wells.	Yes
Institutional Controls	Groundwater Use Control	Land Use Control/Regulate Well Permits	Plume area is currently within the Base boundary and land use and groundwater use are under Base jurisdiction.	Yes
		Seal/Abandon Existing Wells	No production wells are known to exist in the current or predicted plume area.	No
		Point-of-Use Treatment	No groundwater is extracted from the plume area for any use.	No
		Meetings/Newsletters	Base public relations and environmental management offices have many information avenues to inform workers and residents.	Yes
Containment of Plume	Hydraulic Controls	Passive Drain Collection	No likely receptors downgradient of site. Installation disruptive to base operations. Prohibitive due to groundwater depth.	No
		Minimum Pumping/Gradient Control	Surficial aquifer thickness is limited (5 to 10 ft). Pumping groundwater would not be continuous due to dewatering of aquifer and would require treated water disposal.	No
		Slurry Walls/Grout Curtains	Requires significant disruption of a base operations. Limited effectiveness.	No
	Physical Controls	Sheet Piling	Requires significant disruption to base operations. Limited effectiveness.	No
		Biologically Active Zones	Natural biodegradation of BTEX compounds can be stimulated by allowing contaminated groundwater to flow through an aquifer zone which has enhanced oxygen and nutrient conditions. Not practical for excessive contaminant concentrations.	No

TABLE 6.2 (continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY SITE
SEYMOUR JOHNSON AFB, NORTH CAROLINA

General Response Action	Technology Type	Process Option	Implementability	Retain
In Situ Treatment	Biological	Oxygen and/or Nutrient Enhanced Biodegradation (Biosparging)	Differs from biologically active zone in that oxygen and/or nutrients are injected in source area and allowed to migrate downgradient. Although implementable, the technology may be no more effective than intrinsic remediation.	No
	Chemical/Physical	Intrinsic Remediation	A combination of natural biological, chemical, and physical removal mechanisms which occur to varying degrees on every site. Groundwater sampling at the site indicates that this is a major, ongoing remediation process.	Yes
		Air Sparging (Volatilization)	Injection of air into contaminated aquifer creating a mass transfer of BTEX into air bubbles and into vadose zone. Most effective for plume containment.	No
Aboveground Groundwater Treatment	Groundwater Extraction	Vertical Pumping Wells	Entire groundwater plume is pumped by installing numerous wells with submersible pumps. High cost and major disruption to area. Not effective until residual LNAPL is remediated.	No
		Downgradient Horizontal Drains	See Passive Drain Collection.	No
		Bioreactors	High flow rates require excessive retention times and large reactors. BTEX is often volatilized in these systems.	No
	Biological	Air Stripping	Cost-effective technology for removing varying concentrations of BTEX from groundwater at high flow rates. Permitting for air emissions may be required.	Yes
		Activated Carbon	Cost prohibitive for more concentrated BTEX. Creates a carbon disposal problem.	No
		UV/Ozone Reactors	High flow rates require excessive retention times and large, expensive reactors.	No

TABLE 6.2 (continued)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY SITE
SEYMOUR JOHNSON AFB, NORTH CAROLINA

General Response Action	Technology Type	Process Option	Implementability	Retain
Aboveground Treatment	Direct Discharge to Industrial Waste Water Treatment Plant (IWWTP)	IWWTP	Viable option when an IWWTP is available and capable of handling BTEX and hydraulic loading. Groundwater extraction is not planned.	No
	Discharge to IWWTP or Sanitary Sewer	IWWTP Sanitary Sewer	Viable option when access to industrial sewer exists and hydraulic loading is acceptable. Same as above. Viable option when access to sanitary sewer exists and hydraulic loading is acceptable. Same as above.	No No
Treated Groundwater Disposal	Treated Groundwater Reinjection	Vertical Injection Wells	Injection wells subject to clogging, high maintenance, and permitting.	No
		Injection Trenches	Less clogging than wells, but large trenches are required and can be subject to injection well permitting.	No
	Discharge to Surface Waters	Storm Drains	Viable option but generally requires discharge permitting. Groundwater extraction is unlikely.	No
		Dual-Pump Systems	Best suited for sites with > 1 foot mobile LNAPL and where aboveground groundwater treatment already exists	No
Source Removal/Soil Remediation	Mobile LNAPL Recovery	Skimmer Pumps/Bailers/Wi cks	Best suited for sites with < 1 foot mobile LNAPL and where groundwater pumping is undesirable.	Yes
		Total Fluids Pumping	Best suited for sites with thin saturated zones where excessive groundwater will not be pumped.	No
		Bioslurping	Combined vapor extraction, and mobile LNAPL recovery system has been operated at some sites with limited success. Minimal product at site.	Yes
		Hand Bailing	The limited quantity of mobile LNAPL at the site makes this method cost-effective on a short-term basis.	Yes
		Biological Landfarming	Excavation is feasible at this site. Base operates state-permitted landfarm.	Yes
		Excavation/ Treatment		

TABLE 6.2 (concluded)
INITIAL TECHNICAL IMPLEMENTABILITY SCREENING OF
TECHNOLOGIES AND PROCESS OPTIONS FOR GROUNDWATER REMEDIATION
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY SITE
SEYMOUR JOHNSON AFB, NORTH CAROLINA

General Response Action	Technology Type	Process Option	Implementability	Retain
Source Removal/Soil Remediation (cont'd)	Excavation/ Treatment (cont'd) <i>In Situ</i>	Thermal Desorption	Excavation is feasible at this site; however, this technology is no more effective but more expensive than use of the existing landfarm.	No
		Bioventing	Air injection to stimulate biodegradation of fuel residuals.	Yes
		Soil Vapor Extraction	Sandy soils with a deep groundwater table suggest this option may be successful and economical. Requires expensive off-gas treatment. Included as a component of bioslurping	No

In addition to intrinsic remediation, mobile LNAPL recovery has been proposed under Alternative 1 in order to reduce the volume of fuel hydrocarbons available for future dissolution into site groundwater. This would result in a reduction in future dissolved contaminant concentrations, and allow the processes of natural attenuation to complete the remediation of dissolved contamination over a shorter period of time. Currently, Seymour Johnson AFB personnel use a bailer to manually remove approximately 0.25 to 0.5 gallon of mobile LNAPL from monitoring point MW-13, weekly. Because a fairly extensive body of mobile LNAPL exists at the site, the current recovery program could be expanded to increase effectiveness. Under this alternative, LNAPL recovery would be accomplished by replacing the weekly bailing at one well with a 3- to 5-well automated skimmer system.

Three Bioplume II models are discussed in Section 5. The worst-case model, SETUP16, simulates continuous and unchanging leaching of BTEX from mobile and residual LNAPL. This model predicts that the plume will reach its maximum extent and concentration in approximately 20 years (year 2015) and thereafter become stable. Models SR3 and SR5 simulate complete remediation of source area mobile and residual LNAPL over periods of 3 and 5 years, respectively. Results of both models indicate that natural attenuation will complete the remediation of dissolved BTEX contamination 4 years after source remediation. Because Alternative 1 includes source reduction as well as intrinsic remediation, model SETUP16 is extremely conservative. In addition, the UST system has been removed; therefore, future releases of contaminants into the subsurface should not occur. Given continuing source reduction, actual plume dimensions likely will be smaller than those predicted by model SETUP16, with the plume shrinking back to the source area and BTEX concentrations eventually falling below standards. However, the automated skimmer system would be unlikely to result in total source remediation in only 5 years. Instead, a combination of mobile LNAPL skimming and residual LNAPL weathering/biodegradation could result in complete source reduction in approximately 10 years. On the basis of the SR3 and SR5 models, it is assumed that natural attenuation would eliminate the remaining dissolved BTEX 4 years after the disappearance of the source. On the basis of even the most conservative model, SETUP16, it is unlikely that benzene concentrations exceeding the North Carolina groundwater quality standard of 1 µg/L would migrate more than 300 feet downgradient from the source area. This would be true even if it were assumed that model contaminant concentrations are all benzene rather than total BTEX.

Implementation of Alternative 1 would require the use of institutional controls, such as land use restrictions, and LTM. Land use restrictions may include placing long-term restrictions on soil excavation within the source area and long-term restrictions on groundwater well installations within and downgradient from the source area. The intent of these restrictions would be to reduce potential receptor exposure to contaminants by legally restricting activities within areas affected by site-related contamination.

Fifteen years of annual long-term monitoring would be conducted as part of this remedial alternative to evaluate the progress of natural attenuation processes. Because the only apparent downgradient receptor exposure point is the drainage creek, POC wells should be placed between the source area at the site and the creek, beyond the extent of

predicted plume migration (i.e., approximately 200 feet downgradient from the current plume front). In addition, LTM wells within the existing BTEX plume would be used to monitor the effectiveness of intrinsic remediation. LTM and POC wells are further described in Section 7.2. Detection of benzene in excess of 1 µg/L at the POC wells may require additional evaluation and modeling to assess BTEX migration, to determine if any BTEX will reach the drainage creek, and to determine if additional corrective actions would be necessary. Land use restrictions would also require reevaluation.

Public education on the selected alternative will be developed to inform Base personnel and local residents of the scientific principles underlying source reduction and intrinsic remediation. This education could be accomplished through public meetings, presentations, press releases, and posting of signs where appropriate. Periodic site reviews could also be conducted every year using data collected from the long-term groundwater monitoring program. The purpose of these periodic reviews would be to evaluate the extent of contamination, assess contaminant migration and attenuation through time, document the effectiveness of source removal and institutional controls at the site, and reevaluate the need for additional remedial actions at the site.

6.3.2 Alternative 2 - Intrinsic Remediation, Bioslurping, Bioventing, and Institutional Controls with Long-Term Groundwater Monitoring

This alternative is identical to Alternative 1 except that skimming would be replaced with bioslurping and bioventing in order to reduce the volume of mobile and residual LNAPL within the source area. This would be accomplished through the installation and operation of bioslurping and bioventing wells within and around the perimeter of the source area. By reducing the quantity of residual fuel hydrocarbons within the source area, bioslurping and bioventing would reduce the predicted future dissolution of BTEX into the surficial aquifer and therefore shorten the predicted length of time required for natural attenuation processes to degrade dissolved BTEX.

Bioslurping is a bioremediation technique that is applicable for the remediation and removal of measurable layers of mobile LNAPL on groundwater. A bioslurping system consists of a "slurp" tube that extends through a groundwater monitoring well into the LNAPL layer. Product and highly contaminated groundwater are drawn into the tube as air is removed from the tube with a vacuum extraction pump. Recovery of product is enhanced because a vacuum draws product in the formation toward the extraction well, as opposed to relying on gravity flow as required with conventional product recovery systems. Furthermore, product flows along a horizontal path toward the bioslurping extraction well. This reduces the "smearing" associated with the groundwater drawdown created by typical pumping extraction systems. In addition to the removal of LNAPL, as air is removed from the subsurface, oxygenated air is drawn into the pore spaces of the contaminated soils adjacent to the extraction well, promoting aerobic biodegradation (bioventing). Also contaminated soil vapors are removed by the vacuum (soil vapor extraction). Minimal groundwater is extracted using bioslurping technology, resulting in a significant cost advantage over traditional pumping systems, which generate large quantities of wastewater requiring treatment and disposal.

Bioventing is an *in situ* bioremediation technique that is applicable for the remediation of fuel hydrocarbon compounds in vadose zone soils. A regenerative blower is used to inject a small volume of air into wells screened within vadose zone soils. Alternately, a vacuum extraction pump can be used to withdraw a small volume of air from the wells. This process promotes aerobic biodegradation of fuel constituents through the introduction of oxygenated air into contaminated soils.

Results from pilot studies would be used to design a full-scale bioslurping and bioventing system capable of remediation of the mobile and residual LNAPL. A pilot-scale bioslurping test is planned for a second site at Seymour Johnson AFB under a separate AFCEE program. The test will be performed to evaluate the implementability and effectiveness of bioslurping versus conventional LNAPL skimming. A pilot-scale bioventing test could be conducted at the former AGE fueling facility site to evaluate the effectiveness of this technology to remediate residual LNAPL at the site.

At the former AGE fueling facility site, the bioslurping system is conceptualized as an eight-well system manifolded to a liquid-ring vacuum pump. The bioslurping wells would be located in the center of the area underlain by mobile LNAPL (Figure 4.1). An oil/water separator would be used to recover the fuel product. Contaminated water then would be treated with an air stripper. Once the mobile LNAPL recovery is complete, the bioslurping wells could be converted to bioventing wells.

The bioventing system is conceptualized as a series of vertical air-injection wells and vapor monitoring points installed throughout the vadose zone where residual LNAPL contamination is present (Figure 4.2). A small blower would provide a suitable volumetric air flow rate necessary to oxygenate soils.

Model SR5 was developed to estimate the impact of bioslurping and bioventing on the fate and transport of dissolved BTEX in the shallow groundwater. The model assumes that the source area BTEX loading rate is reduced by 20 percent of the original amount each year for a 5-year period. This time period is typical for remediation systems such as bioslurping/bioventing. After 5 years of source removal (2 years of bioslurping followed by 3 years of bioventing), the Bioplume II model predicts that the combination of source reduction and intrinsic remediation within the BTEX plume will significantly reduce its size and concentration. Under this scenario, model results show that it is unlikely that BTEX compounds would migrate more than 250 feet from the source area. The dissolved BTEX plume disappears within 4 years of complete source removal.

As with Alternative 1, institutional controls and LTM would be required. However, due to the shorter time frame, annual groundwater monitoring would not be required for as many years. POC wells would be installed in the same locations alluded to in the previous section.

6.3.3 Alternative 3 - Intrinsic Remediation, Soil Excavation, Bioventing, and Institutional Controls with Long-Term Groundwater Monitoring

This alternative is similar to Alternative 2 except that soil excavation would be used to remove the majority of the mobile and residual LNAPL instead of bioslurping. Like Alternative 2, bioventing would then be used to remove remaining contaminant

concentrations from the vadose zone soils. Removal of LNAPL-contaminated soil could be accomplished rapidly by excavation, followed by 3 years of bioventing to remove the remaining contaminant source. Excavated soil likely could be treated in the Base landfarming operation, which is permitted by the state.

Model SR3 was run to simulate this scenario. Model SR3 is similar to model SR5, except that model SR3 assumes more rapid reductions in the hydrocarbon loading rates to simulate a more aggressive source removal alternative in combination with bioventing. This alternative was assumed to be capable of removing mobile and residual LNAPL contamination from the vadose zone and the saturated zone in approximately 3 years. As a result, in model SR3, the source is reduced by 33.3 percent of the original amount each year for 3 years. After 3 years of source removal, the Bioplume II model predicts that the combination of source reduction and intrinsic remediation within the BTEX plume will significantly decrease in size and concentration. Under this scenario, model results show that it is unlikely that BTEX compounds would migrate more than 250 feet from the source area. This distance is similar to the distance predicted by bioslurping and bioventing (model SR5). However, the maximum BTEX concentration in the SR3 plume after source removal was 750 $\mu\text{g/L}$ (versus 2,984 $\mu\text{g/L}$ for SR5), and again the plume entirely dissipates within 4 years after source removal is completed.

As with Alternatives 1 and 2, institutional controls and LTM would be required. However, due to the shorter time frame, annual groundwater monitoring would not be required for as many years. POC wells would be installed in the same locations alluded to in the previous sections.

6.4 EVALUATION OF ALTERNATIVES

This section provides a comparative analysis based on the effectiveness, implementability and cost criteria for the three previously discussed remedial alternatives. A summary of this evaluation is presented in Section 6.5.

6.4.1 Alternative 1 - Intrinsic Remediation, Mobile LNAPL Recovery, and Institutional Controls with Long-Term Groundwater Monitoring

6.4.1.1 Effectiveness

Section 5 of this document presents the results of the Bioplume II models completed to evaluate the intrinsic remediation alternative at the former AGE fueling facility site. Model results predicted that natural attenuation mechanisms will significantly limit BTEX migration and reduce contaminant mass and toxicity. BTEX (and specifically benzene) concentrations should not exceed state criteria at the POC wells. Groundwater monitoring at the LTM and POC wells will allow for continued evaluation of BTEX migration and ensure the continued effectiveness of this alternative. In the event that BTEX compounds are detected in a POC well at concentrations exceeding North Carolina groundwater quality standards (Table 6.1), this LTM plan does not cease to be protective. The drainage creek is located approximately 850 feet from the former AGE fueling facility site, and it is the only known potential receptor exposure point in the primary

groundwater flow direction. Nevertheless, exceedances at the POC wells would indicate that site conditions should be reevaluated.

The effectiveness of this remedial alternative requires that excavations or drilling within the source area be conducted only by properly protected site workers. Reasonable land use assumptions for the plume area indicate that exposure is unlikely unless excavation or drilling activities bring contaminated soil to the surface. Long-term land use restrictions would be required to ensure that shallow groundwater will not be pumped or removed for potable use within, and approximately 300 feet in all directions from, the existing BTEX plume. Existing health and safety plans should be enforced to reduce risks from any proposed remediation system installation and during installation of additional POC and LTM wells.

Compliance with AFCEE program goals is one component of the long-term effectiveness evaluation criterion. Alternative 1 will satisfy program objectives designed to promote intrinsic remediation as a component of site remediation and to scientifically document natural attenuation processes. Alternative 1 is based on the effectiveness of natural processes that minimize contaminant migration and reduce contaminant mass over time, and the effectiveness of institutional controls. As described earlier, Bioplume II model results suggest that natural attenuation processes will limit further BTEX plume migration to within 300 feet downgradient of the contaminant source area. The sensitivity analyses completed on the Bioplume II model for this site (Section 5) suggests that even under the most conservative (i.e., worst-case) conditions, natural attenuation at the site should reduce contaminant migration so that the plume is unlikely to reach the proposed POC wells.

Apart from the administrative concerns associated with enforcement of long-term land use restrictions and long-term groundwater monitoring programs, this remedial alternative should provide reliable, cost-effective protection. For cost comparison purposes, it is assumed that mobile LNAPL skimming will be performed for a period of 3 years. At that time, all recoverable mobile LNAPL will likely be removed from all site monitoring wells. Residual LNAPL will remain on the site and continue as a source of BTEX contamination in groundwater. Due to natural weathering, this source of BTEX will gradually decrease each year. For costing purposes, Parsons ES assumed that LTM will continue for a 15-year period. This time frame assumes 10 years for residual and mobile LNAPL removal, 4 additional years for dissolved BTEX remediation, and a year of confirmation sampling. During these 15 years, dissolved benzene concentrations within the interior of the BTEX plume should gradually decrease to below the North Carolina groundwater quality standard.

6.4.1.2 Implementability

Alternative 1 is not technically difficult to implement. Manual bailing is currently being used to remove mobile LNAPL from monitoring well MW-13 at the former AGE fueling facility site as described above. Under this alternative, an automated skimming system is proposed for three to five additional wells. The system would include pumps, air compressors, and a storage tank. Installation of POC wells and annual groundwater monitoring are both standard procedures. Long-term management efforts will be required

to ensure that proper sampling procedures are followed. Periodic site reviews should be conducted to confirm the adequacy and completeness of LTM data and to verify the effectiveness of this remediation approach. There also may be administrative concerns associated with long-term enforcement of groundwater use restrictions. Future land use within the source area may be impacted by leaving contaminated soil and groundwater in place. Regulators, Base officials, Base employees, and the public would have to be informed of the benefits and limitations of the intrinsic remediation option. Educational programs are not difficult to implement, and the initial regulatory reaction to this alternative has been positive.

6.4.1.3 Cost

The cost of Alternative 1 is summarized in Table 6.3. A more complete breakdown and present worth analysis of these costs is provided in Appendix F. Capital costs include the construction of the LNAPL recovery system and three new POC wells. The total present worth cost of mobile LNAPL recovery for a period of 3 years and implementation of the LTM plan for 15 years is approximately \$240,000. Also included are the costs of maintaining institutional controls and long-term groundwater monitoring for a total of 15 years.

6.4.2 Alternative 2 - Intrinsic Remediation, Bioslurping, Bioventing, and Institutional Controls with Long-Term Groundwater Monitoring

6.4.2.1 Effectiveness

The effectiveness of the intrinsic remediation, institutional controls, and LTM components of this alternative were described under Alternative 1. Bioslurping and bioventing are innovative technologies for mobile LNAPL removal, residual LNAPL reduction, and control of plume migration. The goal of these two technologies would be to effect the removal of BTEX from the source area so that intrinsic remediation of dissolved contaminants in the groundwater could proceed without the continual infusion of additional contaminants. The model SR5 suggests that reduction of the source would enhance the effectiveness of intrinsic remediation and expedite the decrease in the size of the BTEX plume.

Alternative 2 should provide reliable, continuous protection with little risk from temporary system failures. This alternative is based on the effectiveness of the bioslurping/bioventing system in removing mobile and residual LNAPL from the site within a 5-year period. Once BTEX leaching rates are reduced, intrinsic remediation will then minimize contaminant migration and reduce contaminant mass in groundwater. This alternative also complies with AFCEE program goals because intrinsic remediation remains the predominant remediation method for fuel hydrocarbons dissolved in groundwater at the site. This remedial alternative, however, will result in the generation of drill cuttings, LNAPL, contaminated water, and soil gas, which may require treatment and/or disposal.

TABLE 6.3
ALTERNATIVE 1 COST ESTIMATE
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY SITE
SEYMOUR JOHNSON AFB, NORTH CAROLINA

	<u>Capital Costs (\$)</u>
Install 4 POC wells	\$8,900
Design/Install Mobile LNAPL Recovery System	\$59,300
<u>Operation, Maintenance and Monitoring Costs</u>	<u>Annual Cost (\$)</u>
Continued LNAPL Recovery and Reporting (3 years)	\$20,400
Base Support (3 years)	\$5,000
Conduct Annual Groundwater Monitoring of 6 LTM and 4 POC wells (15 years)	\$6,200
Annual Reporting (15 years)	\$3,300
Maintain Institutional Controls/Public Education (15 years)	\$2,500
<u>Present Worth of Alternative 1 ^{a/}</u>	\$240,000

^{a/} Based on an annual adjustment factor of 7 percent, applied per USEPA (1988) guidance. See Appendix F for breakdown of costs and present worth analysis.

6.4.2.2 Implementability

Alternative 2 is more difficult to implement than Alternative 1. Mobile LNAPL removal would be conducted through bioslurping at the former AGE fueling facility site from wells in the area underlain by free product. The bioslurping system would consist of a series of wells connected by piping to a liquid-ring pump and placed under a vacuum to remove mobile LNAPL (and contaminated groundwater) from the wells. The recovered fluids would pass through an oil/water separator where the petroleum product would be diverted to a storage tank. The contaminated water stream would be treated with an air stripper. Both the bioslurping unit and air stripping unit would require daily maintenance and regular monitoring. Regulatory approval would be required for both the water and air discharged from this system. Once mobile LNAPL had been removed to the extent practicable, the bioslurping wells would be used as the bioventing wells.

Bioventing would be conducted in the portion of the LNAPL plume that is oxygen deficient. The bioventing system would consist of a series of air injection wells connected to a small blower by underground piping. This equipment is fairly common within the environmental industry. Periodic maintenance would be required for the regenerative blower, and weekly system checks are recommended to record operating data such as injection pressures and flow rates. A bioventing pilot test is included within the cost estimate for this alternative so that an effective system could be designed. The technical and administrative implementability concerns associated with the intrinsic remediation and LTM components of this remedial alternative are similar to those discussed in Alternative 1.

6.4.2.3 Cost

The estimated capital and operating costs of Alternative 2 are summarized in Table 6.4. A more complete breakdown and present worth analysis of these costs are provided in Appendix F. Capital costs are the same for construction of four new POC wells, as in Alternative 1. In addition, Alternative 2 includes costs for the 8 wells for the combined bioslurping/bioventing system, a bioslurping vacuum, a bioventing blower, an oil/water separator, and an air stripper. It is assumed that the combined bioslurping/bioventing system would operate for a total of 5 years after installation. The overall cost for installation of the bioslurping/bioventing system, pilot testing, operation of the bioslurping/bioventing system, and implementation of the LTM plan is estimated to be approximately \$425,000 total present worth. Also included are the costs of maintaining institutional controls and long-term groundwater monitoring for a total of 10 years.

6.4.3 Alternative 3 - Intrinsic Remediation, Soil Excavation, Bioventing, and Institutional Controls with Long-Term Groundwater Monitoring

6.4.3.1 Effectiveness

The effectiveness of the intrinsic remediation, bioventing, institutional controls, and LTM components of this alternative were described under Alternatives 1 and 2. Soil excavation is an established technology for reducing source contamination and

TABLE 6.4
ALTERNATIVE 2 COST ESTIMATE
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY SITE
SEYMOUR JOHNSON AFB, NORTH CAROLINA

	<u>Capital Costs (\$)</u>
Install 4 POC wells	\$8,900
Install Test Wells and Conduct Pilot Study	\$19,500
Design Bioslurping/Bioventing System	\$24,200
Install System	\$136,100
<u>Operation, Maintenance and Monitoring Costs</u>	<u>Annual Cost (\$)</u>
Bioslurping System Operation (2 years)	\$57,300
Bioventing System Operation (3 years)	\$8,500
Remediation System Reporting (5 years)	\$5,100
Base Support (5 years)	\$5,000
Conduct Annual Groundwater Monitoring of 6 LTM and 4 POC wells (10 years)	\$6,200
Annual Reporting (10 years)	\$3,300
Maintain Institutional Controls/Public Education (10 years)	\$2,500
<u>Present Worth of Alternative 2 ^{a/}</u>	<u>\$425,000</u>

^{a/} Based on an annual adjustment factor of 7 percent, applied per USEPA (1988) guidance. See Appendix F for breakdown of costs and present worth analysis.

controlling plume migration. Soil excavation would instantaneously eliminate the majority of the continuing source for dissolved BTEX in the groundwater. The model SR3 suggests that reduction of the source would enhance the effectiveness of intrinsic remediation and expedite the decrease in the size of the dissolved BTEX plume. Under this scenario, BTEX plume reductions occur slightly faster than with bioslurping.

Alternative 3 should provide reliable, continuous protection with little risk from temporary system failures. This alternative, however, does not comply well with all of the AFCEE program goals because of the generation of soil waste. In defense of the alternative, the excavated soil would be remediated in the Base landfarming operation, which relies extensively on biological processes to remediate fuel hydrocarbon contamination. Also, intrinsic remediation and bioventing remain the mechanisms for remediating the dissolved fuel hydrocarbon concentrations in site groundwater and the remaining residual LNAPL contamination.

6.4.3.2 Implementability

Alternative 3 would require a short-term disruption of activities at the AGE facility but is otherwise not technically difficult to implement. Mobile and residual LNAPL would be physically removed by excavation of 10 to 13 feet of soil in the central plume area. The area would then be backfilled with clean native soil. Because Seymour Johnson AFB operates a state-permitted land farm on Base, it is assumed that contaminated soil would be treated at the facility. The technical and administrative implementability concerns associated with the bioventing, intrinsic remediation, LTM, and institutional control components of this remedial alternative are similar to those discussed for the previous two alternatives.

6.4.3.3 Cost

The cost of Alternative 3 is summarized in Table 6.5. A more complete breakdown and present worth analysis of these costs are provided in Appendix F. The total present worth cost of Alternative 3 is approximately \$293,000. The cost of Alternative 3 is varied from the costs of Alternative 2 by the addition of excavation, treatment, and replacement of approximately 1,000 cubic yards of contaminated soil and the elimination of the installation, operation, and maintenance costs for the bioslurping system. As in Alternative 2, the bioventing system would operate for 3 years. Also included are the costs of maintaining institutional controls and long-term groundwater monitoring for a total of 8 years.

6.5 RECOMMENDED REMEDIAL APPROACH

Three remedial alternatives were evaluated for remediation of the shallow groundwater at the former AGE fueling facility site. Components of the alternatives evaluated include mobile LNAPL recovery, bioslurping, bioventing, soil excavation, intrinsic remediation, LTM, and institutional controls. Tables 6.2, 6.3, 6.4, and 6.5 summarize the results of the evaluation based upon effectiveness, implementability, and cost criteria. Based on this evaluation, the Air Force recommends Alternative 1 as achieving the best combination of risk reduction, implementability, and cost effectiveness.

TABLE 6.5
ALTERNATIVE 3 COST ESTIMATE
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY SITE
SEYMOUR JOHNSON AFB, NORTH CAROLINA

	<u>Capital Costs (\$)</u>
Install 4 POC wells	\$8,900
Install Test Wells and Conduct Bioventing Pilot Study	\$13,300
Design Bioventing System, Plan Soil Excavation and Procure Bids	\$24,200
Excavate Soil and Install Bioventing System	\$138,400
<u>Operation, Maintenance and Monitoring Costs</u>	<u>Annual Cost (\$)</u>
Bioventing System Operation and Reporting (3 years)	\$13,600
Base Support (3 years)	\$5,000
Conduct Annual Groundwater Monitoring of 6 LTM and 4 POC wells (8 years)	\$6,200
Annual Reporting (8 years)	\$3,300
Maintain Institutional Controls/Public Education (8 years)	\$2,500
<u>Present Worth of Alternative 3</u> ^{a/}	\$293,000

^{a/} Based on an annual adjustment factor of 7 percent, applied per USEPA (1988) guidance. See Appendix F for breakdown of costs and present worth analysis.

All three alternatives rely on natural attenuation processes to reduce migration and toxicity of the dissolved BTEX plume. All three also help to limit further BTEX plume migration by reducing the magnitude of continuing sources. Implementation of Alternatives 2 and 3 are estimated to decrease the time frame for BTEX remediation by 5 and 7 years, respectively; however, both alternatives would require a greater capital expenditure. In addition, the bioslurping component of Alternative 2 requires frequent monitoring and maintenance, while the soil excavation component of Alternative 3 could cause significant disruption of site activities during implementation. Alternative 3 is also considered less desirable because of the significant volume of waste soil that would require treatment.

The final evaluation criterion used to compare each of the three remedial alternatives was present worth cost. It is the opinion of the Air Force that the additional costs of Alternatives 2 and 3 over Alternative 1 are not justified. Although Alternative 3 is only slightly more expensive than Alternative 1 (approximately \$53,000), the inconveniences associated with site disruption and waste generation are considered greater than performing LTM and maintaining institutional controls for an additional 7 years. Implementation of Alternative 1 would require land use and groundwater use controls to be enforced for approximately 15 years after startup of the LNAPL recovery system, along with annual groundwater monitoring for 15 years.

SECTION 7

LONG-TERM MONITORING PLAN

7.1 OVERVIEW

In keeping with the requirements of the preferred remedial alternative for the former AGE fueling facility site (LNAPL recovery and intrinsic remediation with LTM), a long-term groundwater monitoring plan was developed. The purpose of this component of the preferred remedial alternative for the site is to assess conditions over time, confirm the effectiveness of LNAPL recovery and natural processes at reducing contaminant mass and minimizing contaminant migration, assess compliance with regulatory cleanup goals, and evaluate the need for additional remediation.

To demonstrate attainment of site-specific remediation goals and to verify the predictions of the Bioplume II model developed for the former AGE fueling facility site, the LTM plan consists of identifying the location of two separate groundwater monitoring networks and developing a groundwater sampling and analysis strategy. The strategy described in this section is designed to monitor plume migration over time, to verify that intrinsic remediation (in combination with source reduction technology) is occurring at rates sufficient to protect potential receptors, and to meet state regulatory requirements. In the event that data collected under this LTM program indicate that natural processes (in addition to LNAPL recovery) are insufficient to protect human health and the environment, contingency controls to augment the beneficial effects of intrinsic remediation would be necessary.

7.2 MONITORING NETWORKS

Two separate sets of wells will be used at the site as part of remedial Alternative 1. The first set will consist of six LTM wells located within the observed BTEX plume to verify the results of the Bioplume II modeling effort and to ensure that natural attenuation is occurring at rates sufficient to minimize plume expansion (i.e., meet the first level of RAOs for the site). This network of wells will consist of six existing monitoring points screened within the shallow aquifer to provide confirmation and verification of the quantitative groundwater modeling results.

The second set of groundwater monitoring wells are POC wells that will be located downgradient from the source area and upgradient from the drainage creek, as described in the previous section. The purpose of the POC wells is to verify that no BTEX compounds exceeding North Carolina groundwater quality standards migrate to the area where groundwater may affect potential receptors (i.e., meet the second level of RAOs for the site). This network will consist of four groundwater monitoring wells screened across the shallow aquifer.

7.2.1 Long-Term Monitoring Wells

Six existing groundwater wells will be used to monitor the effectiveness of intrinsic remediation in reducing total contaminant mass and minimizing contaminant migration at the former AGE fueling facility site. Monitoring point MW-19 will be used to monitor upgradient groundwater conditions. Monitoring points MW-4 and MW-8 will be used to monitor conditions near the plume source area. Monitoring point MW-17 will be used to evaluate groundwater conditions along the apparent migration pathway to the south, and monitoring points MW-6 and MW-16 will be used to monitor groundwater conditions in the southeasterly flow direction. Figure 7.1 identifies the locations of groundwater monitoring points proposed for LTM. This network will supplement the POC wells to provide early confirmation of model predictions and to allow additional response time if necessary.

7.2.2 Point-of-Compliance Wells

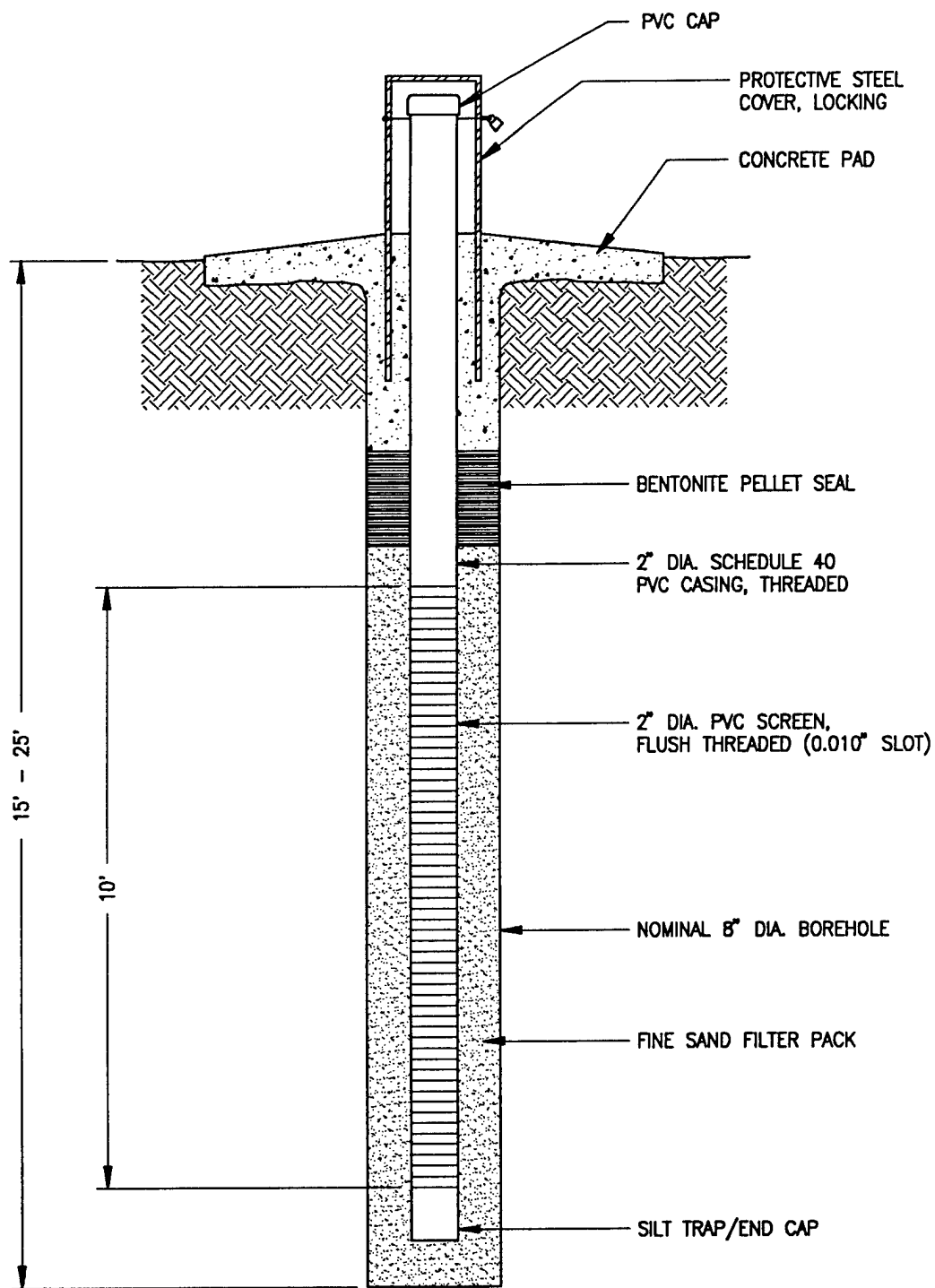
Four POC wells will be used for monitoring groundwater conditions downgradient from the source area at the former AGE fueling facility site (Figure 7.1). One proposed POC well (MW-20) will be located approximately 600 feet to the east of the source area. Two POC wells (MW-21 and MW-22) will be located approximately 600 feet downgradient from the source area southeast from the site (toward the drainage creek). One POC well (MW-23) will be located approximately 450 feet south of the source area in the apparent southerly migration direction. Figure 7.1 shows the proposed locations of the proposed POC wells.

The purpose of the POC wells is to verify that no contaminated groundwater exceeding North Carolina groundwater quality standards migrates beyond the area under institutional control (i.e. approaches the discharge area along the banks of the drainage creek). Although model results suggest that the BTEX plume will not migrate beyond this location at concentrations exceeding chemical-specific regulatory standards, these POC wells are the technical mechanisms used to demonstrate protection of human health and the environment and compliance with site-specific numerical remediation goals.

As with the LTM wells, the POC wells also will be screened in the same hydrogeologic unit as the contaminant plume. Data presented in this report concerning the nature and extent of contamination at the site suggest that a 10-foot screen with approximately 5 feet of screen below the groundwater surface will be sufficient to intercept the contaminant plume at this site. Figure 7.2 is a proposed groundwater monitoring well completion diagram for the new POC wells.

7.3 GROUNDWATER SAMPLING

To ensure that sufficient contaminant removal is occurring at the former AGE fueling facility site to meet site-specific remediation goals, this long-term groundwater monitoring plan includes a comprehensive sampling and analysis plan. Both LTM and POC wells will be sampled and analyzed annually to verify that natural processes are effectively reducing contaminant mass and mobility. Reduction in toxicity will be implied by mass reduction.



Note: Drawing is not to scale.

Figure 7.1

PROPOSED MONITORING WELL COMPLETION DIAGRAM

Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC



**PARSONS
ENGINEERING SCIENCE, INC.**

Cary, North Carolina

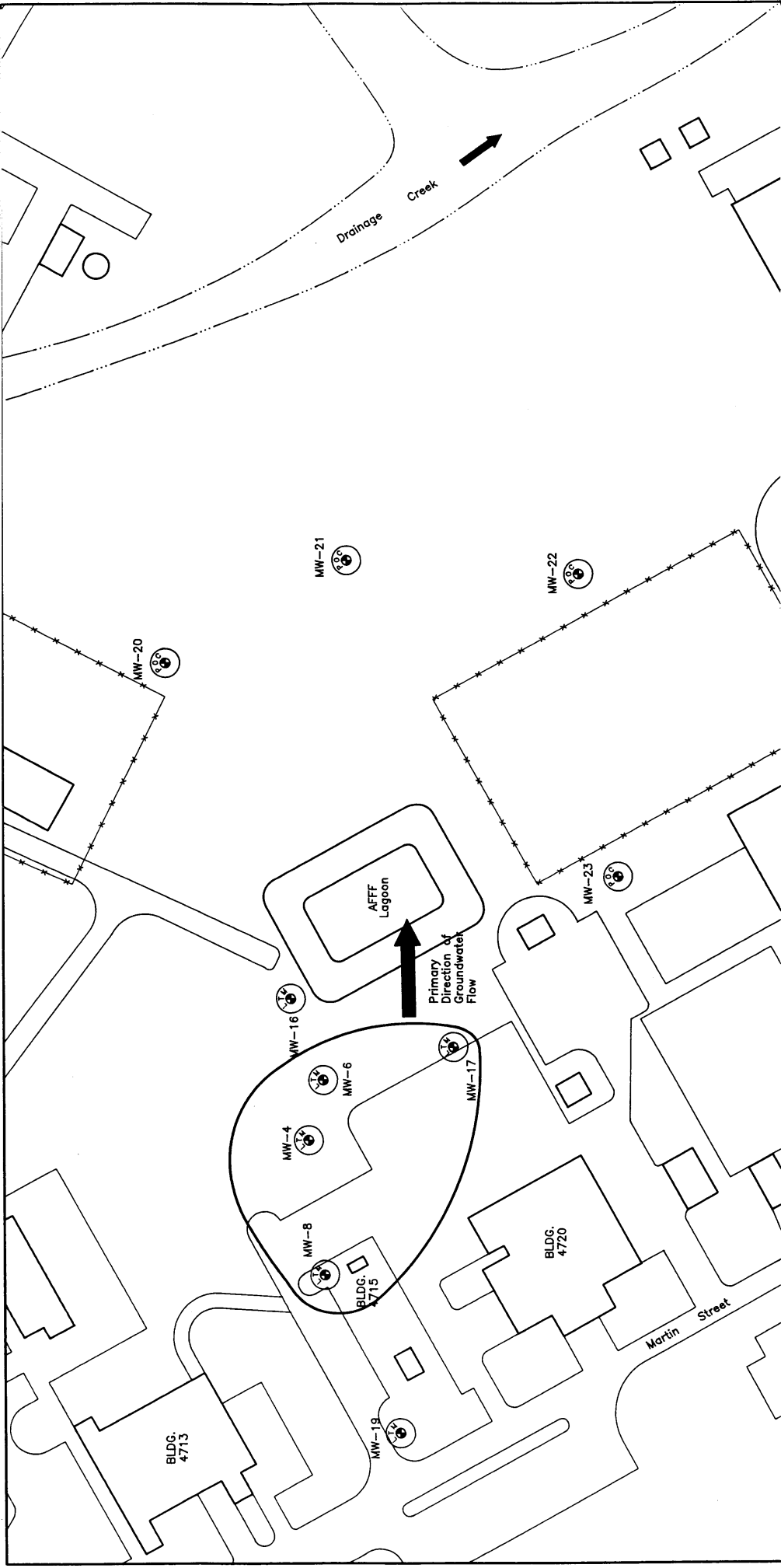
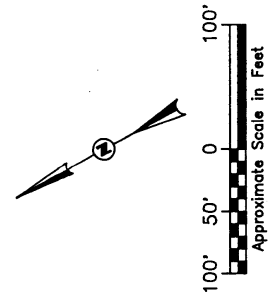


Figure 7.2

**PROPOSED POINT-OF-COMPLIANCE
AND LONG-TERM MONITORING
WELL PLACEMENT**

Intrinsic Remediation EE/CA
Former AGE Fueling Facility
Seymour Johnson AFB, NC

**PARSONS
ENGINEERING SCIENCE, INC.**
Cary, North Carolina



- LEGEND**
- Proposed long-term monitoring well.
 - Proposed point-of-compliance monitoring well.
 - Approximate limit of BTEX plume in groundwater.

The sampling and analysis plan also is aimed at assuring that the selected remedial alternative can achieve site-specific remediation concentration goals for BTEX compounds.

7.3.1 Analytical Protocol

All LTM and POC wells in the LTM program will be sampled and analyzed to determine compliance with chemical-specific state remediation goals and to verify the effectiveness of intrinsic remediation at the site. Water level measurements will be made during each sampling event. Groundwater samples will be analyzed for the parameters listed in Tables 7.1 and 7.2. A site-specific groundwater sampling and analysis plan should be prepared prior to initiating the LTM program.

7.3.2 Sampling Frequency

Each of the LTM and POC wells will be sampled once each year for 15 years. If the data collected during this time period supports the anticipated effectiveness of the intrinsic remediation alternative at this site, the sampling frequency can be reduced to once every five years for all wells in the LTM program, or eliminated. If the data collected at any time during the monitoring period indicate the need for additional remedial activities at the site, sampling frequency should be adjusted accordingly.

TABLE 7.1

**LONG-TERM MONITORING ANALYTICAL PROTOCOL
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY SITE
SEYMOUR JOHNSON AFB, NORTH CAROLINA**

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Ferrous (Fe^{2+})	Colorimetric A3500-Fe D	Field only	Elevated ferrous iron concentrations may be indicative of the anaerobic biodegradation process of iron reduction	Annually	Collect 100 mL of water in a glass container; acidify with hydrochloric acid per method	Field
Ferrous (Fe^{2+})	Colorimetric HACH 25140-25	Alternate method; field only	Elevated ferrous iron concentrations may be indicative of the anaerobic biodegradation process of iron reduction	Annually	Collect 100 mL of water in a glass container	Field
Temperature	E170.1	Field only	Metabolism rates for microorganisms depend on temperature	Annually	N/A	Field
Dissolved Oxygen	Dissolved oxygen meter	Refer to Method A4500 for a comparable laboratory procedure	The oxygen concentration is a data input to the Bioplume II model; concentrations less than 1 mg/L generally indicate an anaerobic pathway	Annually	Collect 300 mL of water in biochemical oxygen demand bottles; analyze immediately; alternately, measure dissolved oxygen <i>in situ</i>	Field
pH	E150.1/SW9040, direct reading meter	Protocols/Handbook methods ^{a/}	Aerobic and anaerobic processes are pH-sensitive	Annually	Collect 100–250 mL of water in a glass or plastic container; analyze immediately	Field
Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system	Annually	Collect 100–250 mL of water in a glass or plastic container	Field
Nitrate (NO_3^{-1})	IC method E300 or method SW9056; colorimetric, method E353.2	Method E300 is a Handbook method; method SW9056 is an equivalent procedure	Substrate for microbial respiration if oxygen is depleted	Annually	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C; analyze within 48 hours	Fixed-base

TABLE 7.1 (continued)
LONG-TERM MONITORING ANALYTICAL PROTOCOL
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY SITE
SEYMOUR JOHNSON AFB, NORTH CAROLINA

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Sulfate (SO_4^{2-})	IC method E300 or method SW9056 or HACH SulfaVer 4 method	Method E300 is a Handbook method; method SW9056 is an equivalent procedure. HACH method is Photometric	Substrate for anaerobic microbial respiration	Annually	Collect up to 40 mL of water in a glass or plastic container; cool to 4°C	Fixed-base or field (for HACH method)
Redox potential	A2580 B	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of groundwater influences and is influenced by biologically mediated reactions; the redox potential of groundwater may range from more than 200 mV to less than -400 mV	Annually	Collect 100-250 mL of water in a glass container, filling container from bottom; analyze immediately	Field
Methane	RSKSOP-114 modified to analyze water samples for methane by headspace sampling with dual thermal conductivity and flame ionization detection.	Method published and used by the US Environmental Protection Agency Robert S. Kerr Laboratory	The presence of methane suggests BTEX degradation via an anaerobic pathway utilizing carbon dioxide (carbonate) as the electron acceptor (methanogenesis)	Annually	Collect water samples in 40 mL volatile organic analysis (VOA) vials with butyl gray/Teflon-lined caps (zero headspace); cool to 4°C	Fixed-base
Aromatic hydrocarbons (BTEX)	Purge and trap GC method SW8020	Handbook method; analysis may be extended to higher molecular weight alkylbenzenes	BTEX is the primary target analyte for monitoring natural attenuation; BTEX concentrations must also be measured for regulatory compliance	Annually	Collect water samples in a 40 mL VOA vial with zero headspace; cool to 4°C; add hydrochloric acid to pH 2	Fixed-base

a/ Protocol methods are presented by Wiedemeier *et al.*, 1995

TABLE 7.2

**POINT-OF COMPLIANCE MONITORING ANALYTICAL PROTOCOL
INTRINSIC REMEDIATION EE/CA
FORMER AGE FUELING FACILITY SITE
SEYMOUR JOHNSON AFB, NORTH CAROLINA**

Analyte	Method/Reference	Comments	Data Use	Recommended Frequency of Analysis	Sample Volume, Sample Container, Sample Preservation	Field or Fixed-Base Laboratory
Temperature	E170.1	Field only	Well development	Annually	N/A	Field
Dissolved Oxygen	Dissolved oxygen meter	Refer to method A4500 for a comparable laboratory procedure	The oxygen concentration is a data input to the Bioplume model; concentrations less than 1 mg/L generally indicate an anaerobic pathway	Annually	Collect 300 mL of water in biochemical oxygen demand bottles; analyze immediately; alternately, measure dissolved oxygen <i>in situ</i>	Field
pH	E150.1/SW9040, direct reading meter	Protocols/Handbook methods ^{a/}	Aerobic and anaerobic processes are pH-sensitive	Annually	Collect 100–250 mL of water in a glass or plastic container; analyze immediately	Field
Conductivity	E120.1/SW9050, direct reading meter	Protocols/Handbook methods	General water quality parameter used as a marker to verify that site samples are obtained from the same groundwater system	Annually	Collect 100–250 mL of water in a glass or plastic container	Field
Redox potential	A2580 B	Measurements are made with electrodes; results are displayed on a meter; samples should be protected from exposure to atmospheric oxygen	The redox potential of groundwater influences and is influenced by biologically mediated reactions; the redox potential of groundwater may range from more than 200 mV to less than -400 mV	Annually	Collect 100–250 mL of water in a glass container, filling container from bottom; analyze immediately	Field
Aromatic hydrocarbons (BTEX)	Purge and trap GC method SW8020	Handbook method; analysis may be extended to higher molecular weight alkybenzenes	BTEX is the primary target analyte for monitoring natural attenuation; BTEX concentrations must also be measured for regulatory compliance	Annually	Collect water samples in a 40 mL VOA vial with zero headspace; cool to 4°C; add hydrochloric acid to pH 2	Fixed-base

a/ Protocol methods are presented by Wiedemeier *et al.*, 1995

SECTION 8

CONCLUSIONS AND RECOMMENDATIONS

This report presents the results of an EE/CA conducted to evaluate the use of intrinsic remediation (natural attenuation) for remediation of fuel-hydrocarbon-contaminated groundwater at the former AGE fueling facility site, Seymour Johnson AFB, North Carolina. Specifically, the finite-difference groundwater model Bioplume II was used in conjunction with site-specific geologic, hydrologic, and laboratory analytical data to simulate the migration and biodegradation of fuel hydrocarbon compounds dissolved in groundwater. Groundwater contaminant and geochemical data strongly suggest that aerobic biodegradation of fuel hydrocarbons is occurring at the site. In addition, the data also suggest that anaerobic biodegradation is occurring via sulfate reduction, methanogenesis, and iron reduction.

To collect the data necessary for the intrinsic remediation demonstration, Parsons ES collected and analyzed soil and groundwater samples from the site. Site-specific geologic, hydrologic, and laboratory analytical data were then used in the Bioplume II numerical groundwater model to simulate the effects of advection, dispersion, sorption, and biodegradation on the fate and transport of the dissolved BTEX plume. Extensive site-specific data were used for model implementation. Model parameters that could not be obtained from existing site data were estimated using widely accepted literature values for sediments similar to those found at the site. Conservative aquifer parameters were used to construct the Bioplume II models for this study. Therefore, the model results presented herein represent conservative predictions of groundwater BTEX plume migration.

For one simulation (model SETUP16), it was assumed that BTEX compounds will continue to enter the aquifer at a constant rate equivalent to the loading rate used to produce the initial calibrated model. Therefore, the results presented for SETUP16 represent a worst-case scenario, in which the BTEX plume achieves its maximum extent and concentration in approximately 20 years and thereafter stabilizes. Throughout this scenario the leading edge of the plume reaches no further than 300 feet downgradient of the source area before stabilizing. For a second simulation (model SR5), it was assumed that BTEX loading rates were eliminated by a combined bioslurping and bioventing system over a 5-year period. A third simulation (model SR3), assumed that BTEX loading rates were eliminated over a 3-year period by using a combination of soil excavation and a bioventing system. These time periods were considered practical limits for currently available remedial technologies based on the current LNAPL distribution, the relatively thin saturated zone, presence of clayey and silty strata below the site, and limited site access due to the ongoing AGE operations.

Models SR5 and SR3 produced similar results. Both models predict that the dissolved BTEX constituents will completely degrade via natural attenuation within approximately 4 years of complete source removal regardless of the source removal scenarios. This occurs because biodegradation rates due to replenished DO concentrations and anaerobic

decay eventually exceed the rate at which dissolved BTEX concentrations are introduced into the aquifer. Actual dissolved BTEX degradation rates observed during LTM at the site will probably be greater than predicted by model SETUP16 and possibly less than those predicted by model SR5 or model SR3. This will result in faster removal rates of the BTEX compounds and a shorter plume migration distance than predicted by SETUP16.

The results of this study suggest that natural attenuation of BTEX compounds is occurring at the former AGE fueling facility site to the extent that the dissolved concentrations of these compounds in groundwater should be reduced to levels below current regulatory standards long before potential downgradient receptors could be adversely affected (i.e., the potential contaminant migration pathway will not be complete at the potential receptor exposure point described in Section 6.2). Based on the distance to the only potential receptor exposure point (the drainage creek approximately 850 feet downgradient), rates of BTEX plume migration and degradation predicted by model SETUP16, and the cost effectiveness of Alternative 1 as compared to the other remedial alternatives (on a present worth basis), the Air Force recommends implementation of a mobile LNAPL skimming system coupled with natural attenuation, institutional controls, and LTM as the remedial option for the former AGE fueling facility site.

To accomplish the recommended alternative, construction activities and groundwater use in and downgradient from the source area should be restricted for a period of approximately 15 years or until groundwater contaminant concentrations decrease below North Carolina groundwater quality standards for BTEX. Groundwater samples will be collected during LTM to monitor plume migration, allowing continual reevaluation of this time frame.

To verify the results of the Bioplume II modeling effort, and to ensure that natural attenuation is occurring at rates sufficient to meet regulatory compliance goals, groundwater samples from six existing monitoring points (MW-4, MW-6, MW-8, MW-16, MW -17, and MW -19) have been designated for LTM. Analytical parameters are listed in Table 7.1. In addition, four new POC wells should be sampled annually for the parameters listed in Table 7.2. If dissolved BTEX concentrations in the POC wells are found to exceed the North Carolina groundwater quality standards of 1 $\mu\text{g/L}$ for benzene, 1,000 $\mu\text{g/L}$ for toluene, 29 $\mu\text{g/L}$ for ethylbenzene, or 530 $\mu\text{g/L}$ for total xylenes, additional evaluation or corrective action may be necessary at this site.

SECTION 9

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